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## ABSTRACT

This instructional package was designed to develop a basic understanding of solar energy systems. It consists of seven instructional units, a glossary and a collection of transparency masters for use with the units. Each unit presents: (1) unit objective and specific objectives; (2) background material for student reading; (3) student assignment sheet; (4) student activities; (5) a unit test for mastery; and (6) answers to the assignment sheet and test. Units include topics such as: (1) importance of sun angle; (2) collector design; and (3) solar heating systems. (MP)

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# Understanding Solar Energy Systems

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TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) AND USERS OF THE ERIC SYSTEM."

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# **Understanding Solar Energy Systems**

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Note: The underlined terms in each unit can be found in the Terms and Definitions section of that unit and are compiled in the Glossary as well.



Preface to  
Solar Energy Instructional Module  
"Understanding Solar Energy Systems"

In 1977 a research project was undertaken to determine manpower needs in emerging energy fields in Arizona and New Mexico. It was found that one of the fields with the greatest growth potential was in solar energy. While there is not a need for "new occupations" in the solar energy industry, there is a real need for those persons in existing skill areas to be trained to have a basic understanding of solar energy systems. This need cuts across all types of occupations from sales to assembly to installation.

This instructional package is to help meet this need. It is designed for programs of post high school technical education and adult education programs. It could be used in both pre-service and in-service installation of solar energy systems but to provide a basic understanding of such systems.

Laurie Keaton  
Everett D. Edington

Acknowledgments

Special appreciation is extended to Bill Jackson of the New Mexico State Department of Education and to Roger Lambert of the Wisconsin Vocational Studies Center for their evaluations of the instructional module.

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UNIT I  
USING SOLAR ENERGY

UNIT OBJECTIVE

After completion of this unit, the student should be able to explain why solar energy should be developed as an energy source and describe some characteristics of solar radiation. This knowledge will be evidenced by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

Upon completion of this unit the student will learn to

1. Associate correct definitions with the common terms relating to solar energy.
2. Distinguish between renewable and nonrenewable energy sources.
3. Name some uses of solar energy.
4. Identify correct statements about solar radiation.
5. Identify accurate statements about problems associated with using solar energy.

## 1. Terms and Definitions

Btu - British thermal unit, a measure of heat

Biomass conversion - energy from the sun is stored through the process of photosynthesis in plants, i.e., in organic material. Chemical processes can be used to change the organic material to simpler forms with an accompanying release of energy.

Diffuse radiation - the solar radiation striking the surface of the earth after its direction has been changed by reflection and scattered by particles in the atmosphere--nondirectional rays.

Direct radiation - direct or parallel rays from the sun.

Energy - the ability to do work.

Insolation - the amount of solar radiation actually striking the surface of the earth.

Nonrenewable energy source - a substance found in nature which cannot be replenished and which can be used to obtain energy in some form. Coal, gas, uranium are examples of nonrenewable energy sources.

Photovoltaic - direct conversion of the sun's energy to electricity.

Radiation - any object which is warmer than its surroundings transmits heat waves (similar to light waves, but invisible) and, thus, emits energy. Heat transfer occurs by photons.

Renewable energy source - a substance which occurs in nature and the supply of which cannot be depleted by use.

Solar constant - the amount of solar energy striking the outer atmosphere of the earth varies only slightly and can be treated as a constant.

Thermal pollution - the discharge of heated waste into the natural environment at a temperature detrimental to existing ecosystems.

Watts - a measure of power in the metric system (e.g., a 25-watt lightbulb)

## Information Sheet

### 2. Importance of Solar Energy

The oil embargo of 1973 brought to the attention of the American people how dependent the United States has become on imported oil. Since that time, efforts have been made to assess the nation's energy needs and supplies. With this focus on the question of the availability of energy resources in this country has come an increased interest in solar energy.

Those energy sources now used--coal, gas, and uranium--are available only in fixed quantities. When that quantity is used up, there will be no more. For this reason, these are called nonrenewable energy sources. These energy sources present problems not only because they are nonrenewable energy sources, but also because they create problems. The burning of fossil fuels pollutes the atmosphere. The waste from nuclear-fired power plants presents hazards. All contribute to the thermal pollution of our environment. Thermal pollution can result from high temperature exhaust gases (e.g., air pollution from smokestacks) or from high temperature water effluent (e.g., water pollution from nuclear coolants).

On the other hand, solar energy is a renewable resource. In using the sun's energy, man will not exhaust the supply. Not only is solar energy plentiful, but also its use does not create pollution problems. The sun is the original source of almost all of the earth's energy.

### 3. Applications of Solar Energy

Man has made use of energy obtained from the sun for thousands of years, especially to heat water and to dry food materials. Wind energy and geothermal energy are forms of solar energy. Both are used today for a number of purposes (e.g., pumping and heating water). Other applications of energy obtained directly from the sun include the generation of electricity through solar-thermal applications or photovoltaic cells. Also, synthetic fuels can be obtained from solar energy in bio-mass conversions to methanol or indirect combustion of cellulose.

The application of solar energy considered here will be for heating and cooling buildings, heating of domestic hot water, and heating of water for swimming pools.

#### 4. Solar Radiation

Energy is transmitted from the sun to the earth by radiation. Solar radiation is transmitted from the sun in wavelengths, of which visible light represents only a small portion. The intensity of the radiation reaching the upper surface of the earth varies slightly because the sun's output varies. Also, the distance between the sun and earth varies because of the elliptical nature of the earth's orbit about the sun.

These variations are considered to be so minor that the amount of solar radiation reaching the outer atmosphere is treated as a constant. The solar constant equals very nearly 429.2 Btu's per square foot per hour, or 1,353 watts per square meter. It is the intensity of solar radiation striking a plane that is perpendicular to the sun's rays at a distance equalling the average distance of the surface of the earth's outer atmosphere from the sun (see Transparency 1.1).

Although the amount of solar radiation striking the earth's outer atmosphere is relatively constant, not all of that energy actually arrives at the surface of the earth. Almost one-half of the energy either is reflected by particles in the atmosphere back into space or is absorbed by material in the earth's atmosphere (see Transparency 1.2).

Insolation is the amount of solar radiation which actually strikes the earth. Insolation, the solar radiation actually reaching the earth, is of three types: direct radiation or parallel rays, diffuse radiation or non-directional rays, and rays reflected from the ground or from building surfaces (see Transparency 1.3).

The amount of insolation available at any given point on the earth's surface is affected by: 1) the purity of the earth's atmosphere, 2) by the distance the radiation must travel through the atmosphere, and 3) by the angle at which solar radiation strikes the earth's surface. As the radiation travels through the earth's atmosphere, energy is absorbed by particles in the atmosphere. How much is absorbed depends on the amount of water vapor, dust particles, or other matter present in the atmosphere.

Not only do the water vapor and dust particles absorb energy but also, these particles will reflect or deflect some of the sun's rays.



Thus some of the solar radiation is lost when the solar rays are reflected back into space. Other rays become diffuse, or nondirectional. How many rays become diffuse or are reflected depends upon the purity of the atmosphere (Transparency 1.3).

The distance the solar radiation must travel through the earth's atmosphere affects the amount of insolation available. The distance traveled affects how much radiation will be lost through absorption and reflection. It also affects how much diffusion of the solar rays will occur.

How far the rays must travel through the atmosphere is determined by the season of year and time of day. If the sun is low in the sky (close to the horizon), the radiation must travel a greater distance through the atmosphere before striking the surface of the earth (Transparency 1.4).

Also, radiation is most effective if the rays strike a surface perpendicular to the direction the rays are traveling. The energy available decreases the more that the sun's rays vary from the perpendicular (as measured by the cosine of the angle). Therefore, direct or parallel rays are of greater energy value than are diffuse or nondirectional rays. Transparencies 1.5 and 1.6 give a visual representation of the importance of the tilt of the receiving surface.

The length of time radiation strikes a surface must also be considered when discussing the amount of insolation available at any given point on the surface of the earth. This fact again indicates that the angle at which radiation is striking the earth and the season of year are of great importance. These factors affect how much insolation is available for use as an energy source and will be discussed in Unit 2.

##### 5. Problems in Using Solar Energy

Solar radiation is sufficiently diffuse that large surfaces are needed to collect the available energy. For example, in Albuquerque, New Mexico, one square meter (approximately 3' x 3') will supply only two percent of

the heating needs for an average house. On the other hand, the total solar energy striking the roof and south wall of the house is five to ten times more energy than is used in an average house for all purposes!

Solar energy is intermittent. Energy arrives only during the daylight hours and during periods of cloudy weather or winter storms, more energy may be lost than gained. For this reason, storage or auxiliary heating systems are essential.

At present, solar energy systems are best suited for low temperature operation. Some work is being done to develop solar furnaces which concentrate solar radiation to obtain extreme high temperatures. For use in dwellings, however, a low temperature technology is most suitable at present.

## ASSIGNMENT SHEET

1. Why should we develop the sun's energy as an energy resource?
2. Explain why we can talk about the "solar constant."
3. Tell why only about one-half of the solar radiation which strikes the earth's atmosphere actually arrives at the surface of the earth.
4. Explain why the distance the radiation must travel through the earth's atmosphere affects the amount of solar energy available at a particular spot on the earth.
5. Name two problems involved in utilizing solar energy.

UNIT TEST--USING SOLAR ENERGY

1. Match definitions to terms

- \_\_\_ a. Energy
- \_\_\_ b. Nonrenewable energy source
- \_\_\_ c. Photovoltaic
- \_\_\_ d. Radiation
- \_\_\_ e. Direct radiation
- \_\_\_ f. Diffuse radiation
- \_\_\_ g. Insolation
- \_\_\_ h. Solar Constant
- \_\_\_ i. Renewable energy source
- \_\_\_ j. Biomass conversion

- 1. Direct conversion of solar radiation to electricity.
- 2. Solar energy striking the outer atmosphere of the earth varies only slightly.
- 3. Solar energy stored in organic materials is released through chemical processes.
- 4. Ability to do work.
- 5. Transmission of heat waves from a warmer to a cooler surface.
- 6. The solar energy reaching the surface of the earth.
- 7. Use of the resource to obtain energy will lead to depletion of the resource.
- 8. Sun's rays are reflected and scattered by particles in the atmosphere.
- 9. Naturally occurring source of energy which cannot be depleted.
- 10. Parallel rays from the sun.

2. Indicate with an N those energy sources listed below which are nonrenewable.  
Mark with an R any renewable energy sources included in the list.

- ☐ a. Coal
- ☐ b. Uranium
- ☐ c. Wind
- ☐ d. Gas
- ☐ e. Sun

3. Name three applications of solar energy.

- 1. \_\_\_\_\_
- 2. \_\_\_\_\_
- 3. \_\_\_\_\_

4. Mark with a "T" the following statements about solar radiation which are true. Mark false statements with an "F".

- ☐ 1. All solar radiation which strikes the surface of the earth is direct radiation.
- ☐ 2. The intensity of the radiation reaching the upper surface of the earth's atmosphere does not vary.
- ☐ 3. The intensity of the radiation reaching the upper surface of the earth's atmosphere varies slightly because the sun's output varies and because of the elliptical nature of the earth's orbit around the sun.
- ☐ 4. The solar constant is computed as an average.
- ☐ 5. Very little of the solar radiation striking the surface of the earth's atmosphere is lost by reflection or absorption.
- ☐ 6. As solar radiation travels through the earth's atmosphere the rays become more direct.
- ☐ 7. Radiation is most effective if the rays strike a parallel surface.
- ☐ 8. The greater the distance the solar radiation must travel through the atmosphere, the greater will be the loss of energy through absorption and reflection.



5. Mark the following statements with a "T" if the statement is true, or with an "F" if the statement is false.

- ☐ 1. The amount of solar energy available can be calculated.
- ☐ 2. Large surfaces are needed to collect the available solar energy.
- ☐ 3. The amount of solar energy striking the roof and south wall of an average house is less than the amount of energy normally used by the average household.
- ☐ 4. Storage or auxiliary heating systems are needed because solar energy is not always available for collection.

## ANSWERS TO ASSIGNMENT SHEETS AND UNIT I TEST

### Answers to Assignment 1

The sun's energy is a renewable resource. Man will not exhaust the supply.

### Answers to Assignment 2

The solar energy, which is transmitted to the earth, strikes the surface of the earth's atmosphere at a relatively constant rate. There is a slight variation only as the sun's output of energy varies. There is also some variation in the amount of energy received because the distance between the sun and earth varies owing to the elliptical nature of the earth's orbit. However, these variations are considered so minor that the amount of radiation striking the earth's outer atmosphere can be thought of as a constant and is called the "solar constant".

### Answers to Assignment 3

The amount of solar radiation actually striking the surface of the earth is far less than the amount striking the surface of the earth's outer atmosphere because large amounts of the solar radiation are absorbed by particles in the atmosphere. Also, large amounts of radiation are reflected back into space by clouds or materials in the atmosphere.

### Answers to Assignment 4

As solar radiation travels through the earth's atmosphere, more radiation is absorbed and more rays become diffuse.

### Answers to Assignment 5

Problems associated with the use of solar energy are (1) that solar energy is a diffuse source of energy, thus requiring large surface areas to collect the energy and (2) that solar energy is intermittent, thus requiring storage and even auxiliary heating systems.

Answers To Unit Test 1

- a. 4
- b. 7
- c. 1
- d. 5
- e. 10
- f. 8
- g. 6
- h. 2
- i. 9
- j. 3

Answers To Unit Test 2

- a. N
- b. N
- c. R
- d. N
- e. R

Answers to Unit Test 3 (name three)

- 1. To dry food
- 2. To heat water
- 3. To heat buildings
- 4. Generation of electricity
- 5. To obtain synthetic fuels through biomass conversions
- 6. To cool buildings

Answers To Unit Test 4

- 1. F
- 2. F
- 3. T
- 4. T
- 5. F
- 6. F
- 7. T
- 8. T

Answers to Unit Test 5

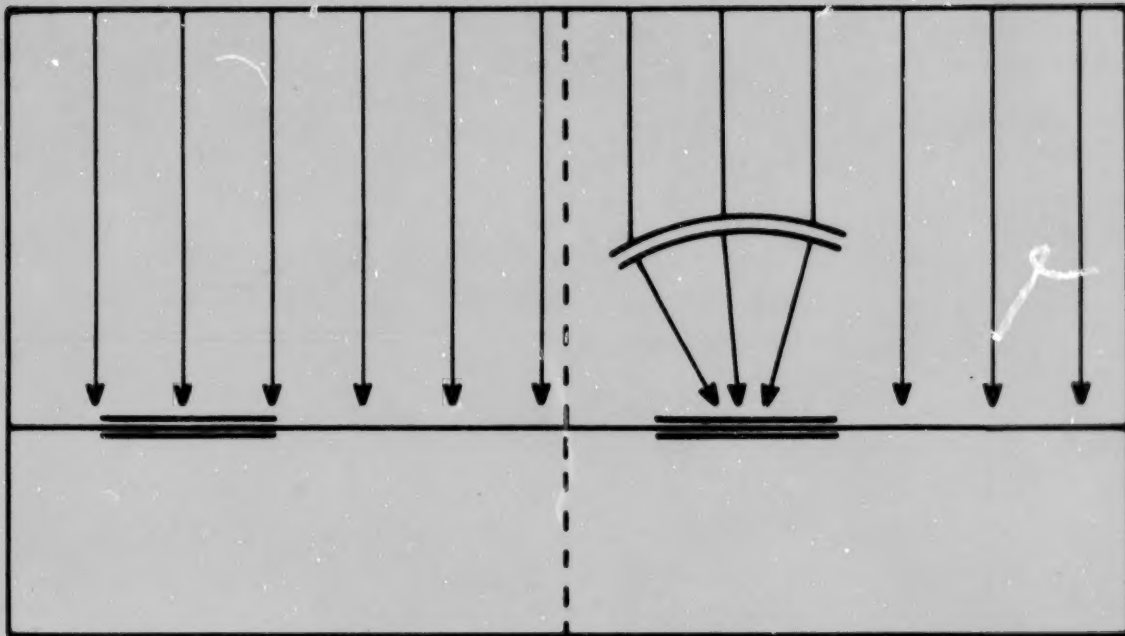
- 1. T
- 2. T
- 3. F
- 4. T

## References

AIA Resource Corporation. May 1976. Solar Dwelling Design Concepts.  
Prepared for the United States Department of Housing and Urban  
Development, Office of Policy Development and Research. Washington,  
D.C.: U.S. Government Printing Office.

Solar Energy Utilization for Heating and Cooling. 1974.

Compiled by John I. Yellott for the American Society of Heating,  
Refrigerating and Air Conditioning Engineers. Washington, D.C.:  
U.S. Government Printing Office. Reprinted from Chapter 59 of the  
1974 Edition, Applications Volume, of the ASHRAE Guide and Data Book  
series.



## 1. SOLAR CONSTANT

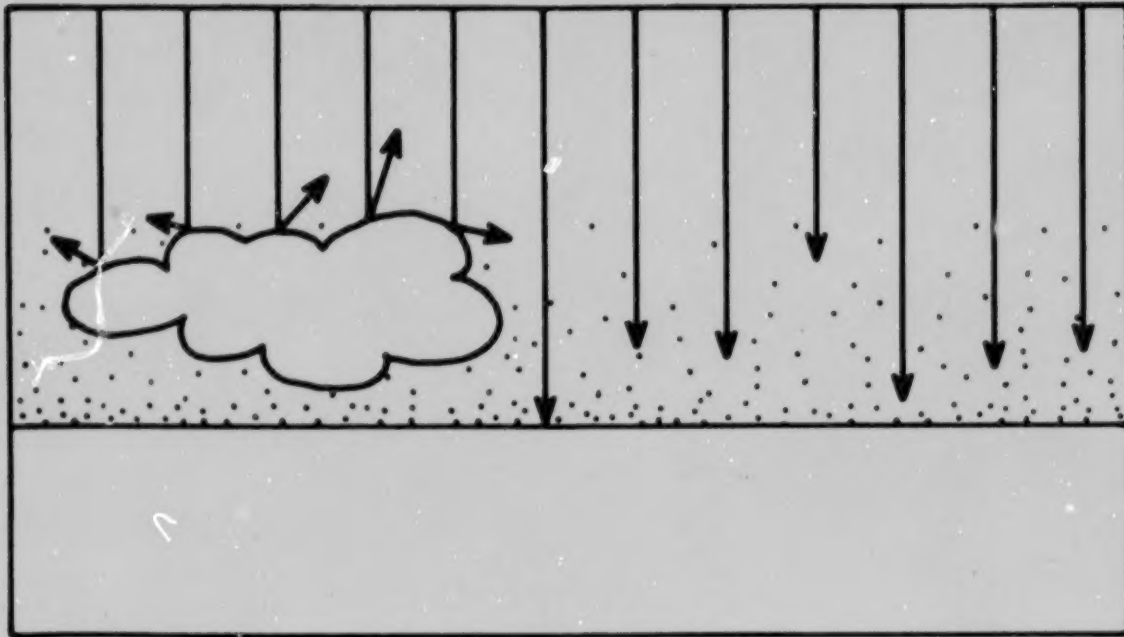
THERE IS A NEARLY CONSTANT AMOUNT OF SOLAR ENERGY STRIKING THE OUTER ATMOSPHERE — 429 BTU PER S.F. PER HOUR — AND THIS QUANTITY IS KNOWN AS THE SOLAR CONSTANT

### NOTE

You cannot increase the amount of solar energy striking a collector of a given size by focusing. You may increase the collector's efficiency, or the temperature of the working fluid.

From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.

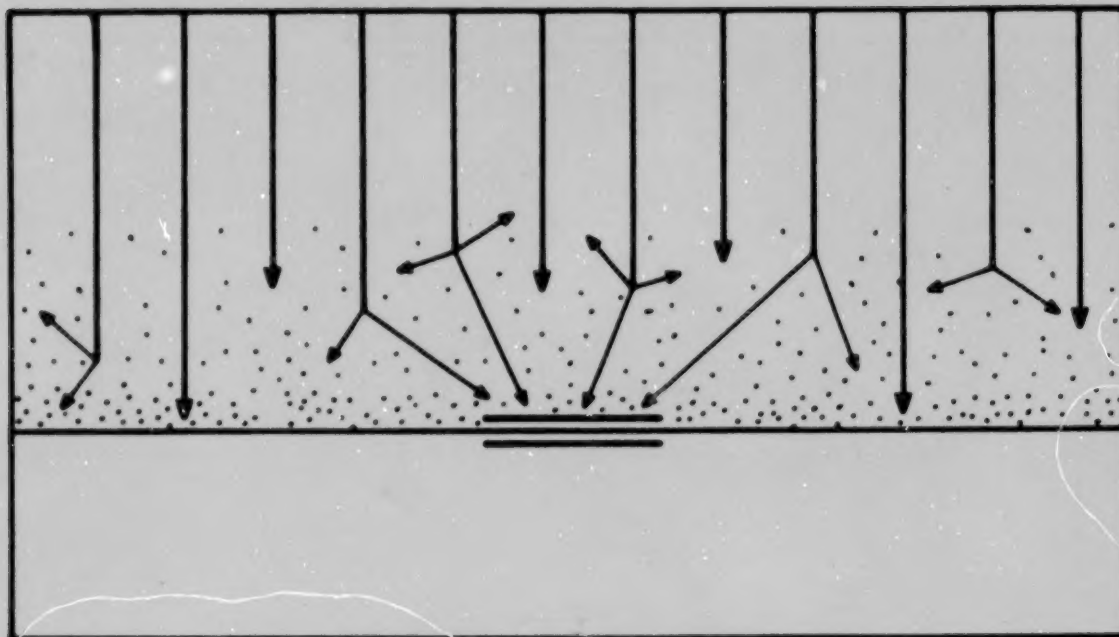




#### **4. ABSORPTION AND REFLECTION**

NEARLY HALF THE SOLAR RADIATION ENTERING THE EARTH'S ATMOSPHERE IS LOST THROUGH ABSORPTION BY MATERIAL IN THE ATMOSPHERE, OR BY REFLECTION FROM CLOUDS.

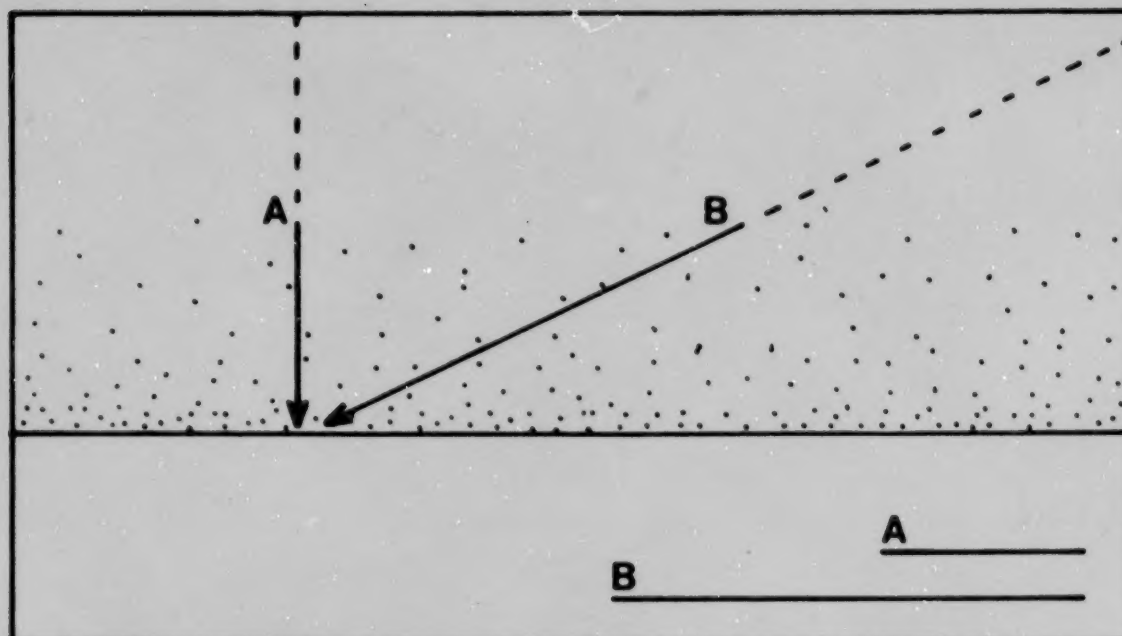
From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.



## 6. DIFFUSE RADIATION

CLOUDS AND PARTICLES IN THE ATMOSPHERE NOT ONLY REFLECT AND ABSORB SOLAR ENERGY, BUT SCATTER IT IN ALL DIRECTIONS BECAUSE OF THIS, SOLAR ENERGY IS RECEIVED FROM ALL PARTS OF THE SKY — MORE SO ON HAZY DAYS THAN ON CLEAR DAYS SUCH RADIATION IS CALLED *DIFFUSE*, AS OPPOSED TO THE NORMAL *DIRECT* RADIATION.

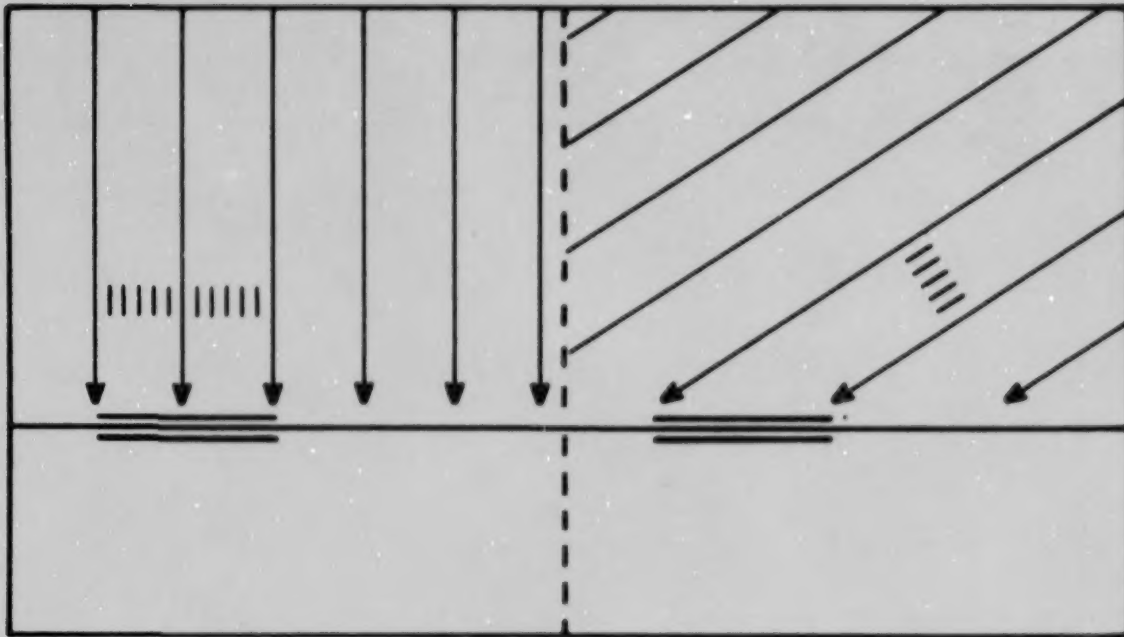
From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.



## 5. LENGTH OF TRAVEL THROUGH THE ATMOSPHERE

MORE SOLAR RADIATION IS LOST BY ABSORPTION AT LOW SUN ANGLES BECAUSE THE LENGTH OF TRAVEL THROUGH THE ATMOSPHERE IS GREATLY INCREASED (THAT IS WHY YOU CAN LOOK DIRECTLY AT THE SUN AT SUNSET.) HIGH ALTITUDES HAVE MORE SOLAR RADIATION FOR THE SAME REASON.

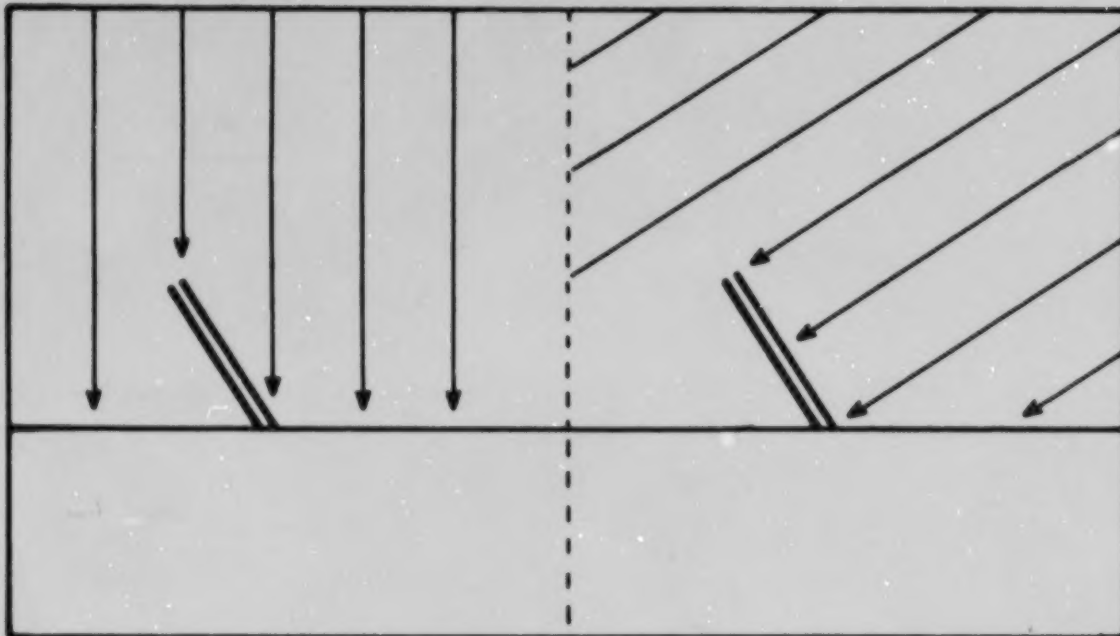
From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.



## 2. COSINE LAW — HORIZONTAL SURFACE

LESS SOLAR RADIATION STRIKES A GIVEN HORIZONTAL AREA AS THE SUN GETS LOWER IN THE SKY. THE AMOUNT CHANGES BY THE COSINE OF THE ANGLE, MEASURED FROM DIRECTLY OVERHEAD.

From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.



### 3. COSINE LAW — TILTED SURFACE

THE SAME LAW APPLIES TO A TILTED SURFACE, SUCH AS A SOLAR COLLECTOR. BY TILTING THE COLLECTOR SO THAT IT IS MORE NEARLY PERPENDICULAR TO THE SUN, MORE ENERGY STRIKES ITS SURFACE.



UNIT II  
LOCATING THE SUN

UNIT OBJECTIVE

After completion of this unit, the student will be able to explain the importance of the position of the sun in relation to the earth for making use of the sun's energy. This knowledge will be evidenced through demonstration and by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

Upon completion of this unit, the student will learn to

1. Associate correct definitions with the new terms in the unit.
2. Identify correct statements about solar radiation and the importance of the earth's location with respect to the sun.
3. Complete sentences referring to the sun's location in the sky.
4. Identify true statements explaining why it is important to know the location of the sun.

Editor's note: An introductory astronomy textbook can be a valuable source for further explanations and additional examples of the material in this unit.

1. Terms and Definitions

Declination angle - the angle between the plane of the earth's rotation around the sun and the earth's equatorial plane in a direction facing the sun.

Earth-sun line - an imaginary line between the center of the sun and the center of the earth.

Equatorial plane - an imaginary plane through the earth's equator and perpendicular to the north-south axis.

Irradiation - exposure to radiant energy.

Latitude - the angular distance north or south from the earth's equator measured through  $90^\circ$ .

Solar altitude - the angle of elevation of the sun above the horizon.

Solar azimuth - the angle on a horizontal surface which measures the difference between the direction of a fixed point (e.g. true south) and the direction of the sun.

Solar noon - that time of day when the azimuth angle is  $0^\circ$ , when the sun is due south of an observer.

## Information Sheet: Locating the Sun

### 2. The Earth's Tilt

As the earth follows its elliptical path around the sun, it also rotates around its own axis. This axis can be defined as a line drawn through the north and south poles. The earth rotates once around its own axis every 24 hours (one day) and once around the sun every 365.25 days (one year).

The axis of the earth's rotation is tilted at an angle of  $23.5^{\circ}$ . This angle is calculated relative to the plane of the earth's orbit around the sun. The direction of tilt of the axis is constant, even as the earth rotates about its own axis and as it travels around the sun (see Transparency 2.1). The constant angle of tilt means that the point on the earth's surface receiving the greatest amount of solar radiation varies. The greatest amount of radiation is received at the point on the surface most perpendicular to the sun's rays (see Transparencies 1.5 and 1.6 in Unit I). Relative to the equator, the point moves north and south between the Tropic of Cancer (latitude  $23.5^{\circ}$  north) and the Tropic of Capricorn (latitude  $23.5^{\circ}$  south). What the sun "sees" is diagrammed in Transparency 2.2.

As the earth orbits about the sun, the tilt of the earth's axis causes the angle between the direct earth-sun line and the equatorial plane to change. This angle, called the angle of declination (Transparency 2.3), changes according to the date of the year. The change in declination determines how much sunlight will strike a surface. Thus, the change in declination explains variations in the intensity of solar radiation at different places on the earth's surface. It explains variations of the temperature at different times of year.

### 3. The Sun's Position In The Sky

The solar azimuth (see transparency 2.4) is an angle on a horizontal surface obtained by measuring the difference between true south and the sun's direction at that moment. The azimuth is defined to be  $0^{\circ}$  at solar noon. The solar altitude is the sun's angle of elevation above the horizon. By knowing the solar azimuth and the solar altitude, one can state

the position of the sun for any latitude at various times of the day. With this information, insolation values (see Unit I) for a given latitude can be obtained. Tables giving the altitude and azimuth angles at different latitudes and for different hours of the day are available in the ASHRAE Handbook of Fundamentals (1972).

#### 4. The Importance of Locating the Sun

Knowledge of the solar azimuth angle and the solar altitude angle, i.e., knowing where the sun will be at a specific time on a particular day, can help in planning a solar dwelling. By knowing the location of the sun at critical times, one can determine at what times house surfaces will be shaded during each season and the intensity of solar radiation available.

For example, during the summer months, the sun may spend a substantial portion of the day to the north of an observer in the northern hemisphere (see Transparency 2.5). Because the sun moves farther north in the summer, south-facing windows can be shaded by an overhang during the heat of the summer day. In this way, solar radiation is prevented from adding to the heat of the interior during the summer months. Yet during the winter months, because the sun has moved farther south, a properly designed overhang will not shade the south-facing windows. This means the direct rays of the sun can be used as a source of energy for warming a dwelling in winter, and yet not add to summer cooling problems.

The position of the sun is important in determining how to place collectors to absorb a maximum amount of solar energy. A surface placed perpendicular to the direct rays of the sun will absorb the greatest amount of energy from the sun. Thus, depending upon the intended use of the energy collected, one may wish to tilt a solar collector so that it receives direct rays from the sun at one time of year and not at another.

In Sunspots (1975), Steve Baer suggests a simple method for illustrating how much surface will be exposed to the sunlight at a specific time. Simply place a rod so that it extends perpendicularly from the flat surface of a board. Keeping the rod perpendicular, tilt the board toward the sun

until there is no shadow. This will be the maximum amount of sunlight for that season and time of day. In this way one can visualize what orientation of a surface will affect the amount of exposure to the sun. Orientation depends on the amount of irradiation desired on a specific surface.



## ACTIVITIES--LOCATION OF SUN

### Activity 1

#### A. Materials Needed

1. Protractor
2. Paper
3. Pencil
4. Model of house, showing overhang, drawn to scale.
5. Window cutouts, to scale: 3', 4', 5', 6' high.
6. Table showing solar position for your Latitude on June 21 and on December 21.

#### B. Procedure

1. Set protractor so that side of house is at center ( $90^{\circ}$ ) of protractor and so that bottom of protractor is at ground level.
2. Reading from table, mark altitude angle at 8:00 a.m. on June 21.
3. Using broken line for angle at 8:00 a.m., draw parallel lines to side of house, maintaining the same altitude angle. Observe where the overhang stops the line, see example in Transparency 2.6.
4. Repeat "2" and "3" for altitude angles at 10:00 a.m. and solar noon on June 21. Use a dotted line for 10:00 a.m. and a solid line for solar noon.
5. Using a second model, follow the same steps for December 21.
6. Place window cutouts on side of house to determine placement for optimum shading.

#### C. What Has Been Learned?

1. What is the effect of the overhang in shading a south-facing window?
2. What could be done in summer to avoid overheating?
3. What can be achieved by a smaller window, placed higher in the wall? Would this interfere with collection of solar radiation in winter? Why?
4. Where will the sun be at 2:00 p.m. on each day?
5. This activity takes only solar altitude into consideration. How does the azimuth angle effect where the sun will be?
6. How could the optimum angle for a flat-plate collector situated on the roof of your building be determined? See Transparency 2.7.

## Activity 2

### A. Materials Needed

1. Protractor
2. Paper
3. Pencil
4. Table showing solar position for your latitude on June 21 and on December 21.

### B. Procedure

1. Establish north-south and east-west lines on a piece of paper.
2. With the protractor, mark off the azimuth angles, using due south as  $0^{\circ}$  and counting the degrees east or west from that point, for various times of day. Use a table for the latitude at which you live (see Transparency 2.8).
3. Mark off the azimuth angles for June 21, March 21, and December 21.

### C. What Has Been Learned?

1. How does the angle at which direct solar radiation strikes a surface affect the amount of radiation available?
2. How does the above question bear upon the solar azimuth?
3. If the altitude and azimuth points for a given date could be plotted on a three-dimensional graph, the resulting line would represent the sun's path across the sky on that date. Transparency 2.9 represents the sun's path on December 21, March and September 21, and June 21. How do these drawings relate to the angles you have plotted for altitude and azimuth?

ASSIGNMENT SHEET: LOCATING THE SUN

1. a. List two ways in which the constant tilt of the earth's axis affects human beings.
- b. Explain the importance of the Tropic of Cancer and the Tropic of Capricorn.
2. What information is needed to state the position of the sun in the sky at a specific time of any day of the year.

UNIT TEST: LOCATING THE SUN

1. Match definitions to terms.

- \_\_\_ a. Declination Angle
- \_\_\_ b. Azimuth
- \_\_\_ c. Solar Noon
- \_\_\_ d. Latitude
- \_\_\_ e. Solar Altitude
- \_\_\_ f. Irradiation
- \_\_\_ g. Insolation

- 1. Angle indicating distance north or south from the earth's equator.
- 2. Exposure to radiant energy.
- 3. Angle between the plane of the earth's rotation around the sun and the earth's equatorial plane in a direction facing the sun.
- 4. The amount of solar radiation actually striking the surface of the earth.
- 5. Angle of sun's elevation above the horizon.
- 6. An angle obtained by measuring from due south and rotating until facing the sun.
- 7. The time of day when the sun is due south of an observer.

2. Mark with a "T" the following statements about solar radiation which are true, and mark with an "F" those statements which are false.

- \_\_\_ a. The earth rotates once around its own axis every 365.25 days.
- \_\_\_ b. The axis of the earth's rotation is tilted  $23.5^{\circ}$ .
- \_\_\_ c. The greatest amount of solar radiation is received at the point on the surface of the earth which is most perpendicular to the direct rays of the sun.
- \_\_\_ d. The tilt of the earth's axis causes the constant change in the angle of declination.
- \_\_\_ e. The spot on the earth most perpendicular to the direct rays of the sun moves from latitude  $23.5^{\circ}\text{N}$  to latitude  $15.5^{\circ}\text{S}$ .
- \_\_\_ f. Variations in hours of daylight and in seasonal temperature differences are explained by the constant change in the angle of declination.

3. Complete the blanks in the following sentences using the words listed below:

1. Solar Azimuth
2. Insolation
3. Solar Altitude
4. Solar Noon

\_\_\_ a. The solar azimuth is defined to be  $0^{\circ}$  at \_\_\_\_\_.

\_\_\_ b. If one knows the (i) \_\_\_\_\_ and (ii) \_\_\_\_\_  
for a given latitude, (iii) \_\_\_\_\_ values can be obtained.

\_\_\_ c. Tables are available which give \_\_\_\_\_ and \_\_\_\_\_  
angles at different latitudes and for different hours of the day.

4. Place an "x" in front of the statements below which are true.

\_\_\_ a. It is impossible to know when house surfaces will be shaded.

\_\_\_ b. South-facing windows can be of value in a solar-heated house  
and still not cause cooling problems in the summer.

\_\_\_ c. In the northern hemisphere, during the summer, the sun can  
actually be north of an observer at certain times of the day.

\_\_\_ d. Roof overhangs are of no value in solar design.

\_\_\_ e. Flat surfaces which are perpendicular to the direct rays of the  
sun will collect solar energy efficiently.



ANSWERS TO ASSIGNMENT SHEET AND UNIT TEST: LOCATING THE SUN

Answer to Assignment 1

- a. The constant tilt of the earth's axis causes season changes and the length of the day.
- b. The Tropic of Cancer is at latitude  $23.5^{\circ}$  North, and the Tropic of Capricorn is at  $23.5^{\circ}$  South. During the year, the length of time required for the earth to move around the sun, the latitudinal spot on the earth nearest the sun moves between these two latitudes. The latitudinal angle is equal to the constant degree of tilt of the earth's axis.

Answer to Assignment 2

- a. Solar azimuth, solar altitude, and latitude.

Answers to Unit Test 1

- a. 3
- b. 6
- c. 7
- d. 1
- e. 5
- f. 2
- g. 4

Answers to Unit Test 2

- a. F
- b. T
- c. T
- d. T
- e. F
- f. T

Answers to Unit Test 3

- a. 4
- b. i. 1      Interchangeable  
    ii. 3  
    iii. 2
- c. 1,3

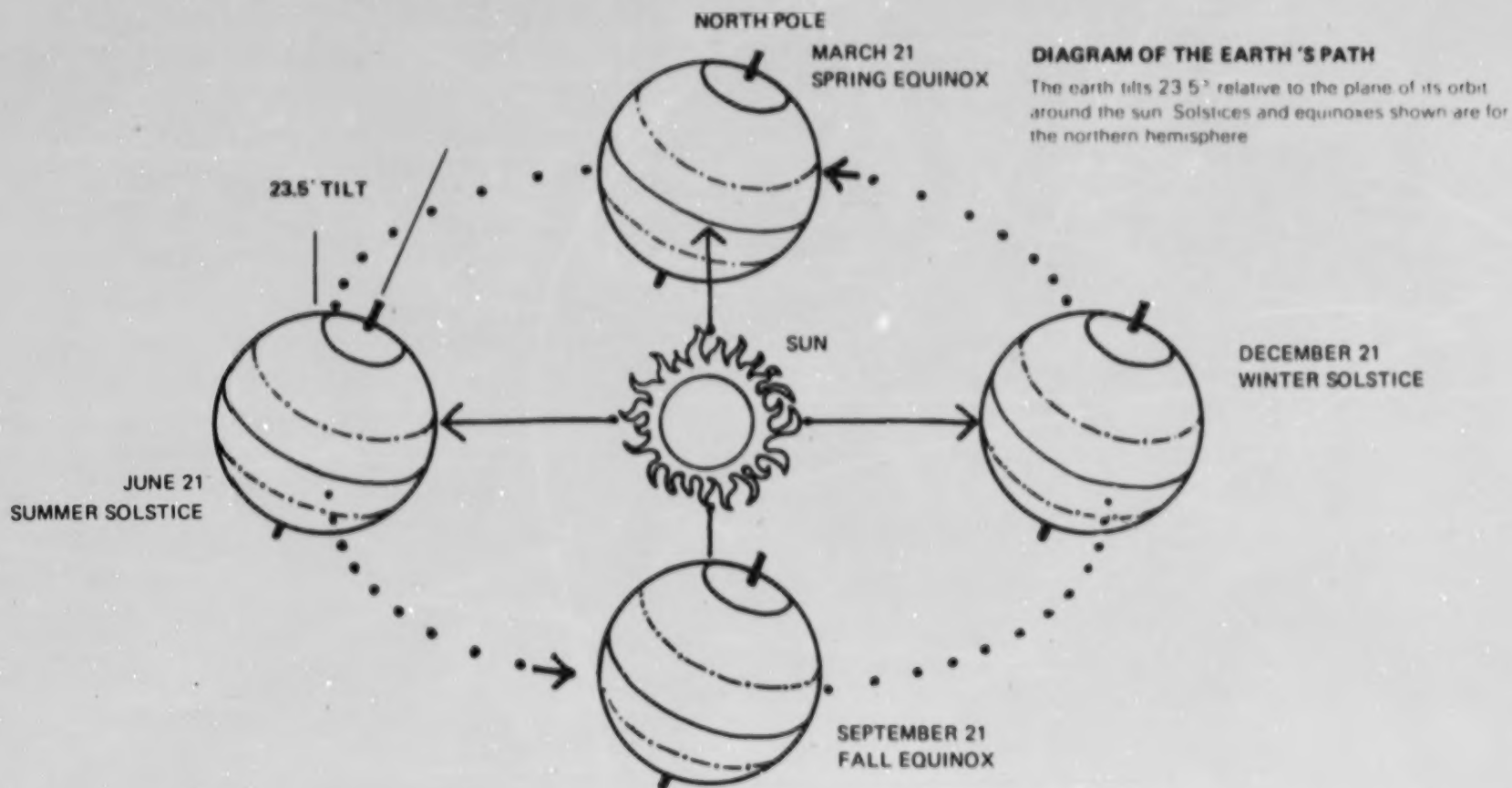
Answers to Unit Test 4

b,c,e

## References

- AIA Research Corporation. May 1976. Solar Dwelling Design Concepts. Prepared for the U.S. Department of Housing and Urban Development, Office of Policy Development, Office of Policy Development and Research. Washington, D.C.: U.S. Government Printing Office.
- Baer, Steve. 1975. Sunspots, Collected Facts and Solar Fiction. Albuquerque, New Mexico: Zomeworks Corporation.
- Balcomb, J. Douglas, James C. Hedstrom, and Hugh S. Murray. November 1976. Pacific Regional Solar Heating Handbook. Prepared for United States Energy Research and Development Administration. Los Alamos, New Mexico: Los Alamos Scientific Laboratory. Available from Superintendent of Documents, U.S. Government Printing Office.
- Solar Energy Utilization for Heating and Cooling. 1974. Compiled by John I. Yellott for the American Society of Heating, Refrigerating and Air Conditioning Engineers. Washington, D.C.: U.S. Government Printing Office. Reprinted from Chapter 59 of the 1974 Edition, Applications Volume, of the ASHRAE Guide and Data Book series.

Transparency 2.1

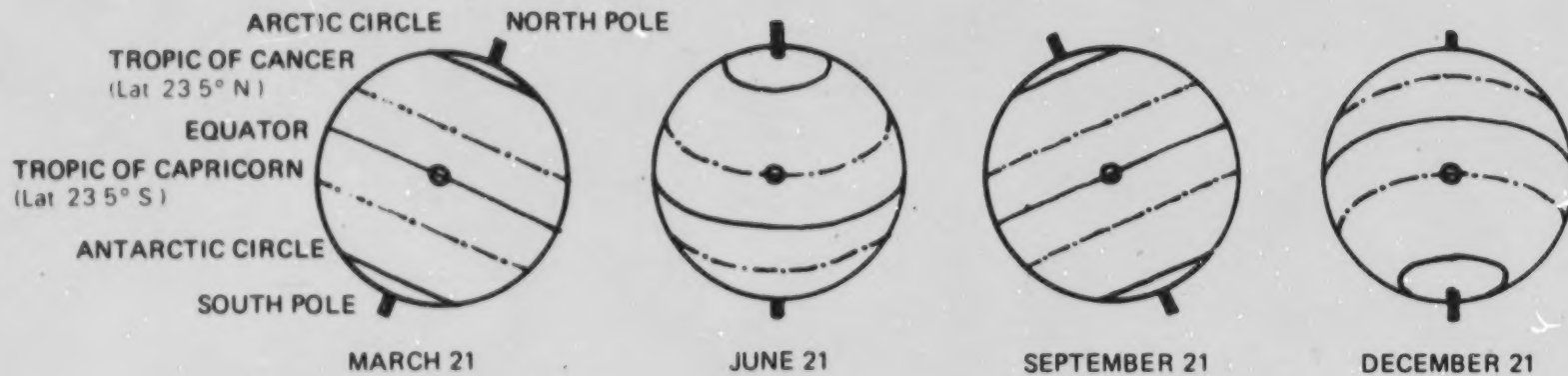


38

37

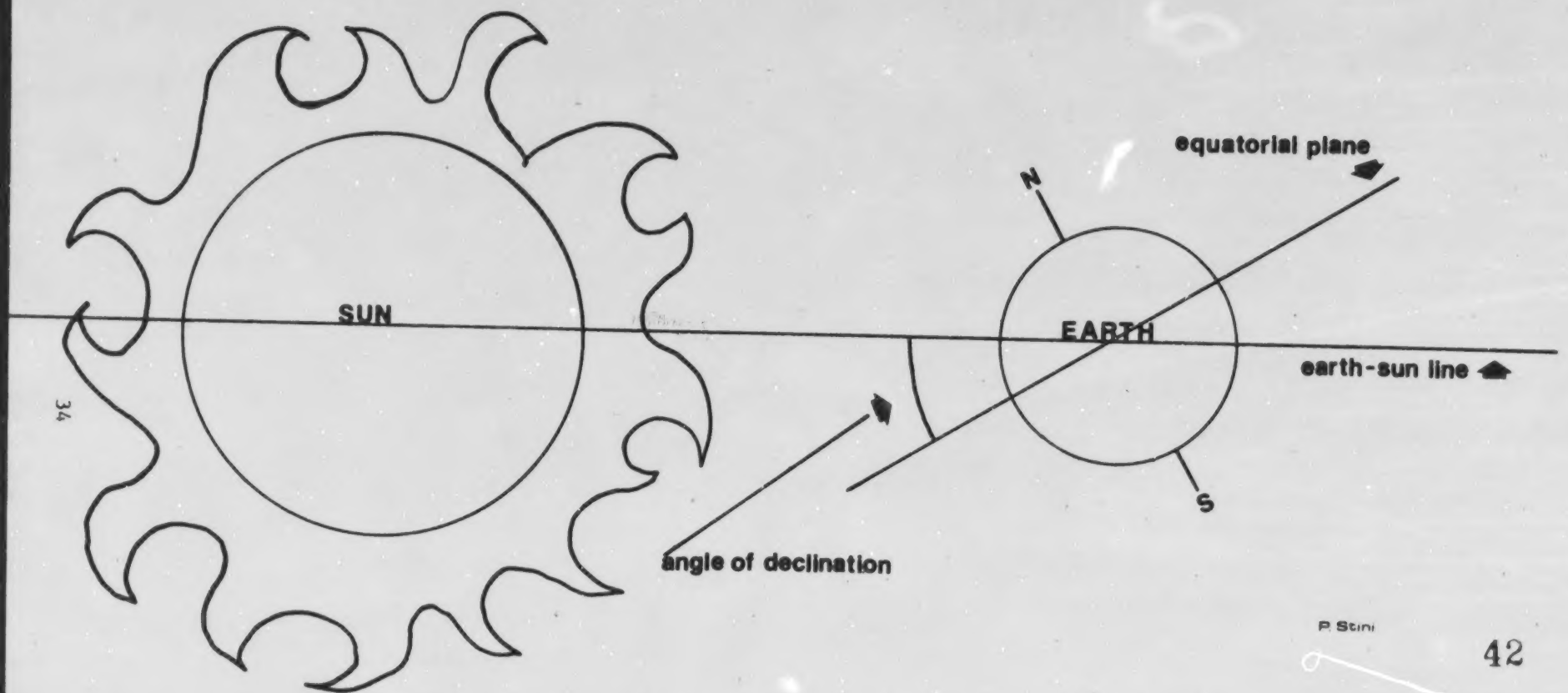
From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C.,  
Government Printing Office, May 1976.

Transparency 2.2



From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C.,  
Government Printing Office, May 1976.

Transparency 2.3

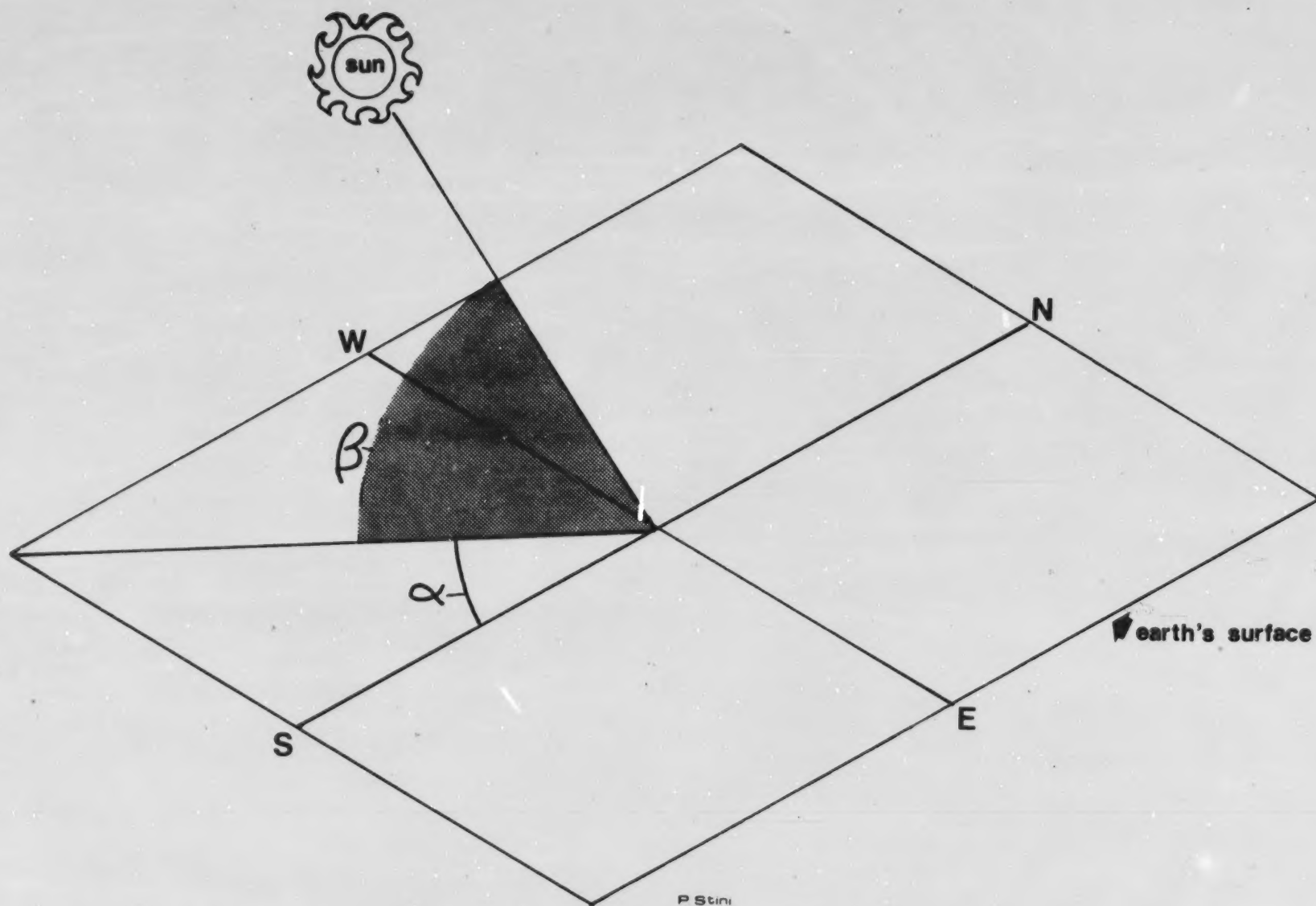


41

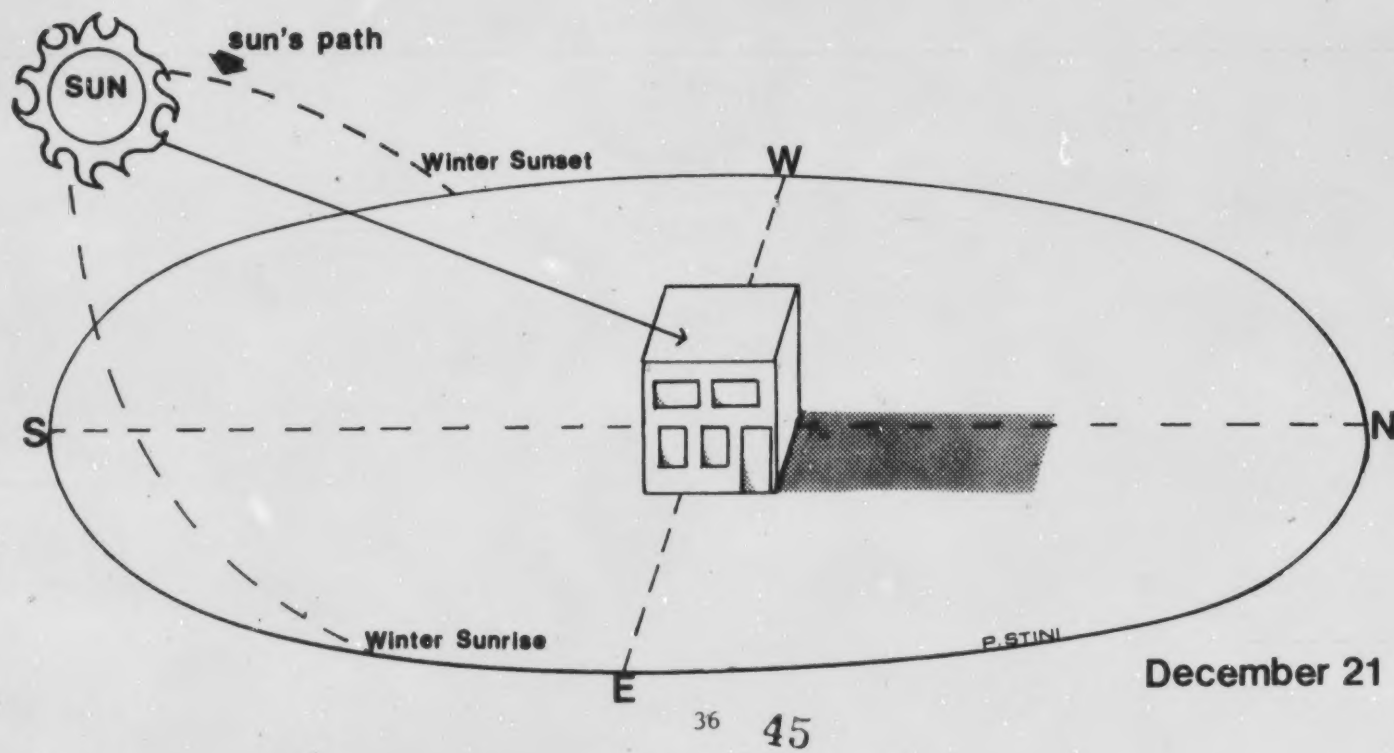
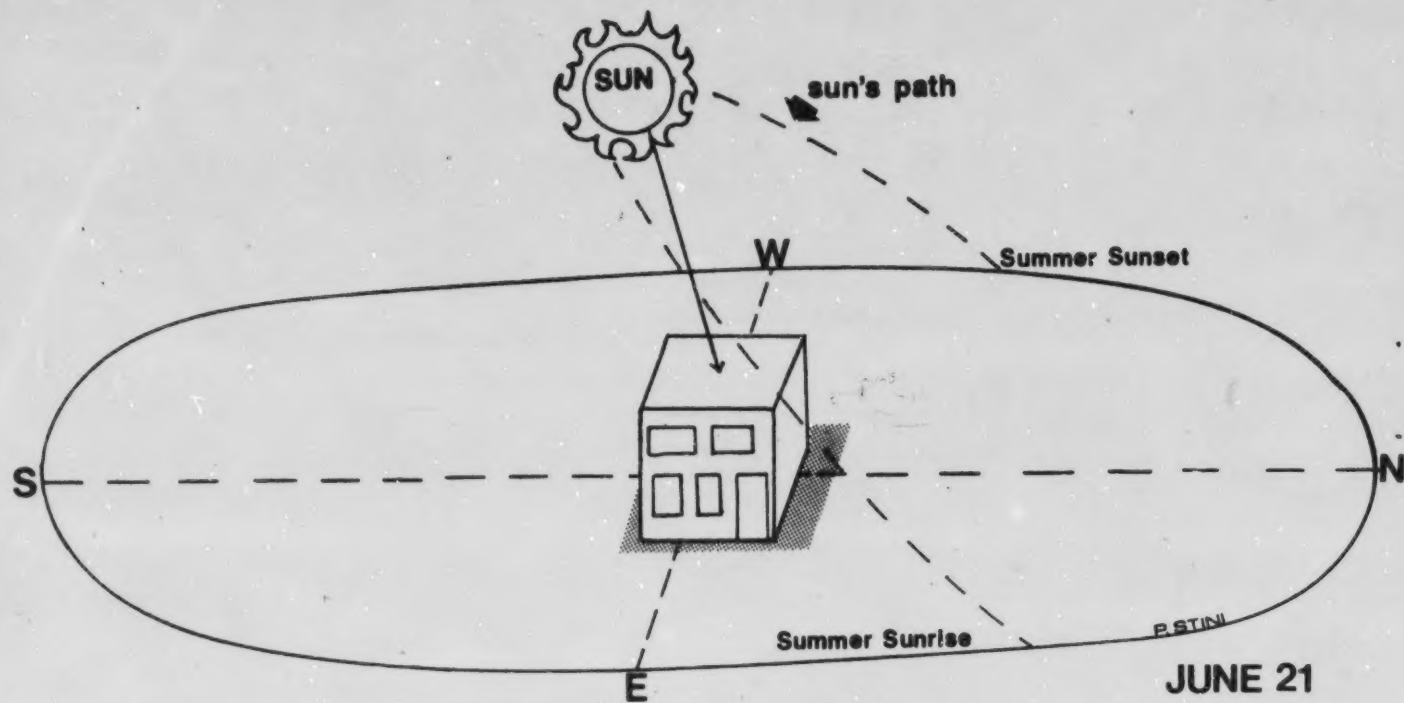
P. Stini

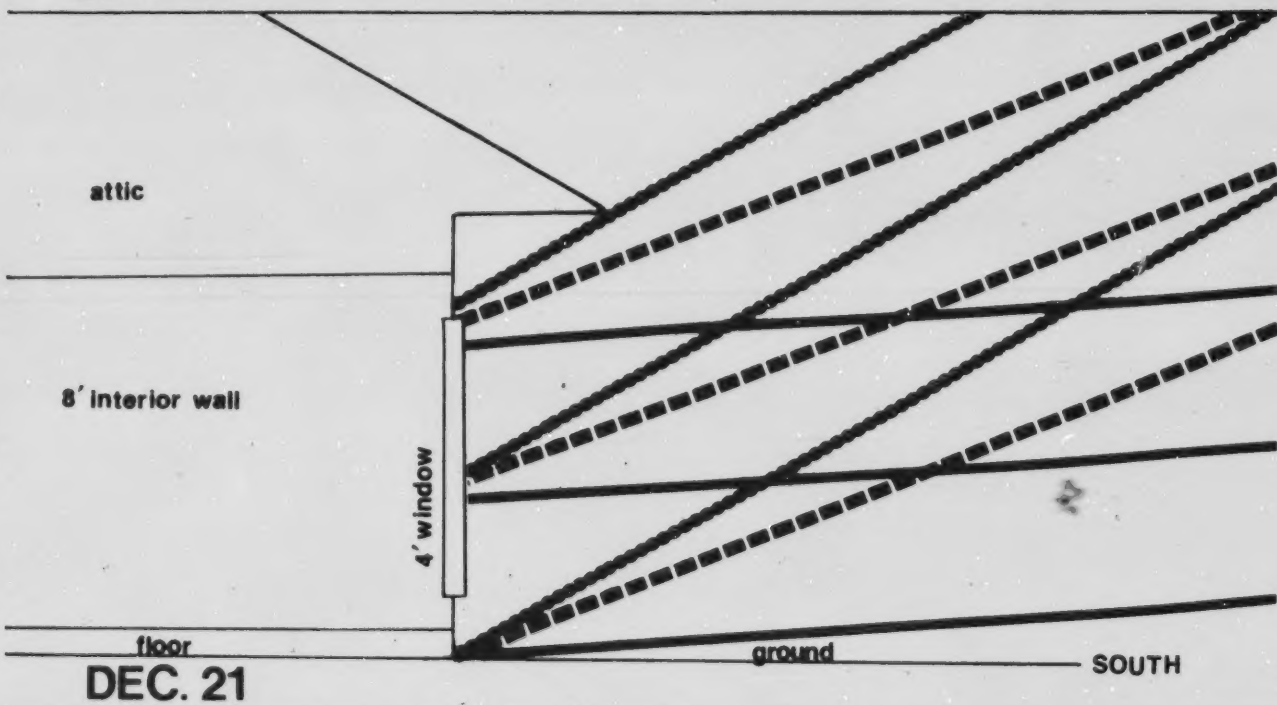
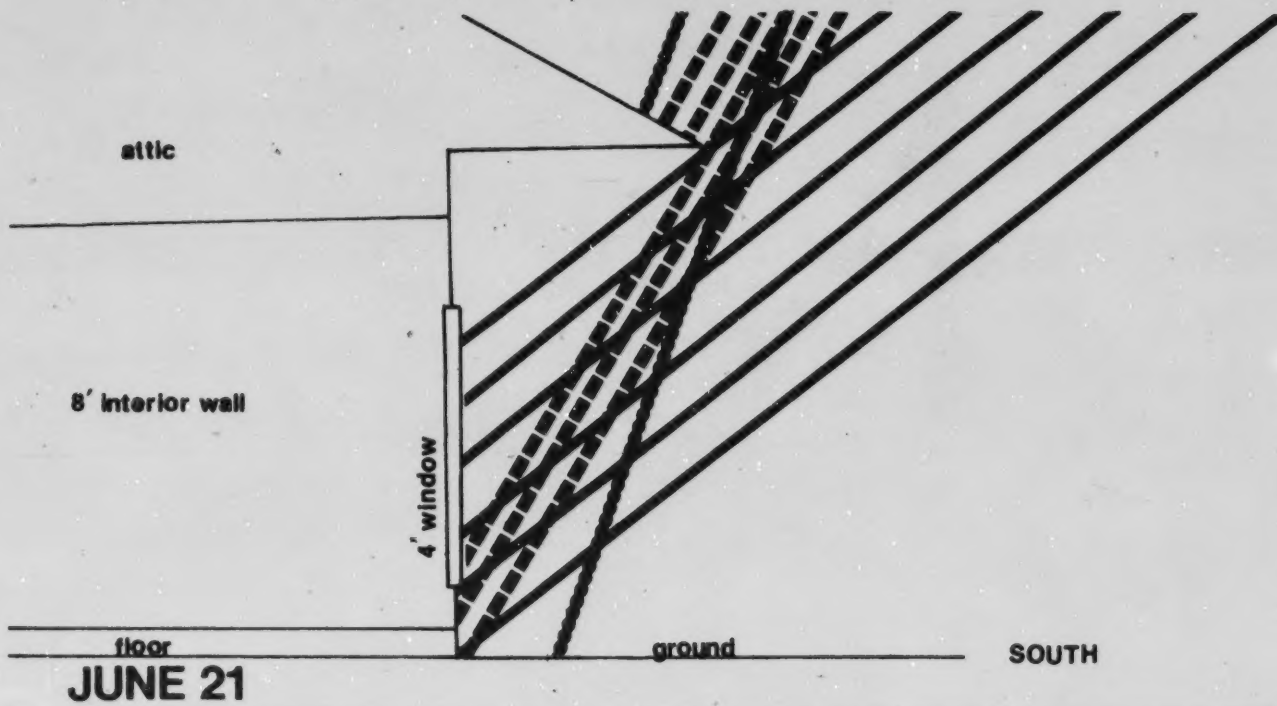
42





35





Direct solar rays on south window of house

———— SOLAR NOON

———— 10 00 A.M.

———— 8 00 A.M.

Latitude 240° NORTH

P. Stini

Transparency 2.7

COLLECTOR TILT

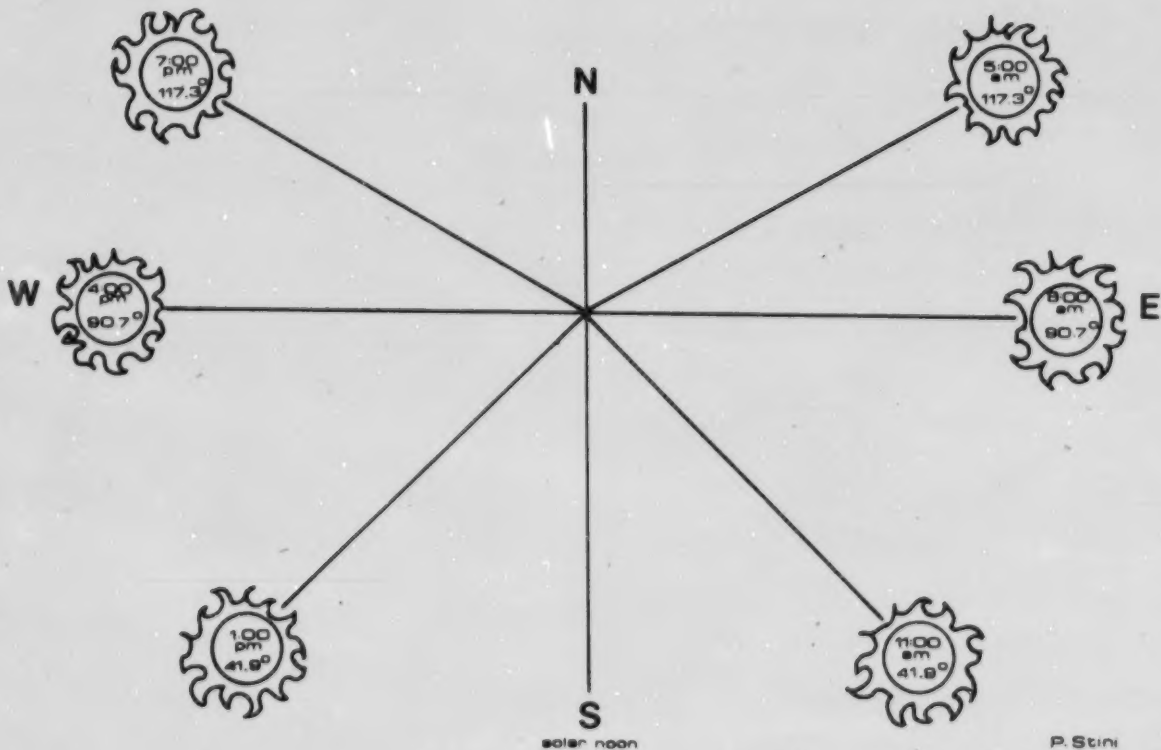
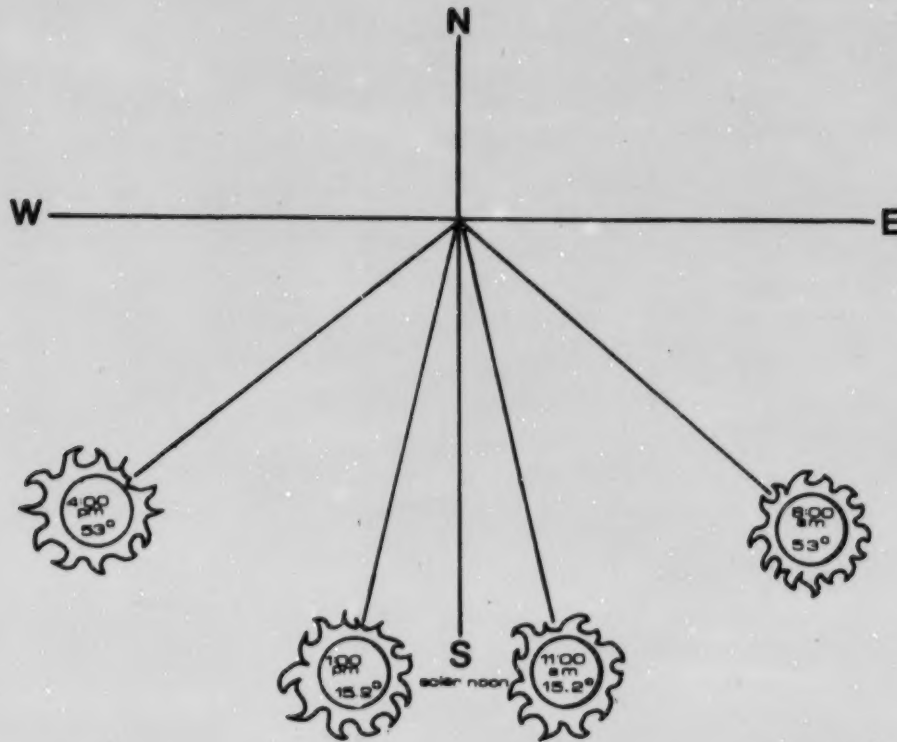
FLAT-PLATE COLLECTOR

DIRECT RAYS OF SUN

HOUSE

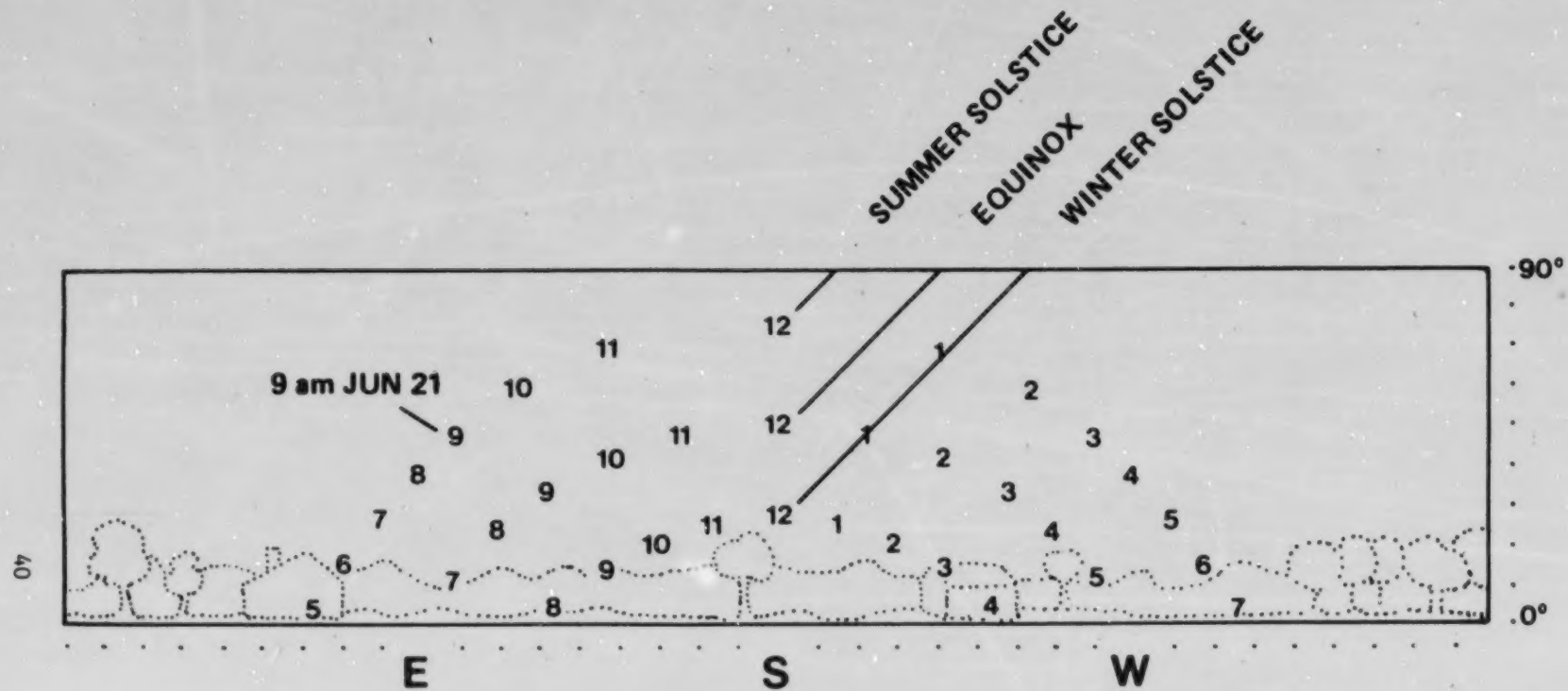
EARTH'S SURFACE

Transparency 2.8



P. Stini





### UNIT III

#### SOLAR ENERGY SYSTEMS

##### UNIT OBJECTIVE

After completion of this unit, the student will be able to explain the principles governing the operation and name the component parts of solar energy systems. This knowledge will be evidenced by scoring 85 percent on the unit test.

##### SPECIFIC OBJECTIVES

After completion of this unit, the student will learn to

1. Associate correct definitions with the new terms in the unit.
2. Identify true statements referring to solar energy systems.

## 1. Terms and Definitions

**Active Solar Energy System** - thermal energy is transported from the collectors to storage and then to the distribution system in a regulated way, using mechanical pumps and thermal controls.

**Collector** - a device for receiving solar radiation and converting it to heat in a fluid.

**Conduction** - heat flows through different materials at varying rates. Copper is an excellent conductor of heat; insulating materials are poor conductors. Heat transfer by conduction occurs only when two surfaces are in direct physical contact because heat transfer is caused by molecular scale vibration.

**Convection** - when two surfaces, one hot, the other cold, are separated by a thin layer of air, moving air currents are established that carry heat from the hot to the cold surface. In convection, heat transfer is by large-scale fluid motion.

**Distribution** - the component in a solar energy system whereby the thermal energy in storage is made available at the point of use.

**Passive Solar Energy System** - heat is transported by natural means, and the components are typically integrated into the basic design of the dwelling, so that few, if any, mechanical devices are needed in the system.

**Radiation** - any object which is warmer than its surroundings transmits heat waves (similar to light waves, but invisible) and, thus, emits energy. Heat transfer occurs by photons.

**Storage** - the component in a solar energy system which retains the solar energy which has been collected for later use either at night or on cloudy days.

**System** - a regularly interacting (or interdependent) group of components forming a unified whole.

## Information Sheet: Solar Energy Systems

### 2. Systems

A system is a regularly interacting (or interdependent) group of components forming a unified whole. We observe systems in nature, e.g., the human body (a biological system), or the pond (an ecological system). In addition, we design systems out of physical parts. An automobile is a physical system made of parts which must work together if the system is to fulfill its design purpose (e.g., if it is to provide transportation from one place to another). To understand a system, it is necessary to understand the parts and how they function. However, it is important to understand not only how the parts function individually, but also, how they function as a unified whole to accomplish the desired end. Very often, individual components may function very well separately and yet not function well at all when joined with the other components in the system. The parts of a system are interdependent. How one component functions will affect how other components function.

A solar energy system is a system designed to use solar radiation as an energy source. The system can be used to heat or cool dwellings, to heat domestic hot water, to heat a pool, and so on. The parts or components of a solar energy system are the collector(Unit IV), storage(Unit V), and distribution (Unit VI). Transparency 3.1 represents schematically a typical solar energy system. Solar radiation is absorbed by the collector, placed in storage, with or without the assistance of a transport medium (e.g., water or forced air) and distributed to the point of use.

Solar energy systems are usually classified as being either active or passive. In an active solar energy system, thermal (heat) energy is transported from the collectors to storage and then to the distribution system in a regulated way using thermal controls. It is necessary to use mechanical devices to pump the gas or liquid transport medium from the collectors to storage and/or to the interior of the dwelling.

In a passive solar energy system, heat is transported by natural means, by radiation, convection, or conduction. The components are typically integrated into the basic design of the dwelling--the windows, walls, floor or ceiling.

## ASSIGNMENT SHEET

1. Name three "systems", and explain why you think they are systems. Include a statement of the design purpose, list the components, and describe very briefly what might happen if one of the components failed or was changed in some way.



## UNIT TEST: SYSTEMS

### 1. Match terms with definitions

- \_\_\_ a. System
- \_\_\_ b. Collector
- \_\_\_ c. Storage
- \_\_\_ d. Distribution
- \_\_\_ e. Active Solar Energy System
- \_\_\_ f. Passive Solar Energy System
- \_\_\_ g. Radiation
- \_\_\_ h. Convection
- \_\_\_ i. Conduction

- 1. Heat is collected, then transported by natural means. The components are integrated into the basic structure of the building.
- 2. Heat transfer caused by molecular scale vibration.
- 3. The component of a solar energy system which carries heat to the point of use.
- 4. Components designed to form a unified whole.
- 5. Component designed to retain heat for long periods of time.
- 6. Moving air currents carry heat from a hot to a cold surface.
- 7. Heat waves transmit energy from a warmer surface to cooler surroundings.
- 8. Collected heat is transported through system by pumps regulated by thermal controls.
- 9. Receives solar radiation and converts it to heat.

2. Check the statements which are correct concerning systems generally or solar energy systems specifically.

- ☐ a. A system is designed to fulfill a specific purpose.
- ☐ b. Not only must the components in a system function well individually, but also they must function effectively within the unified whole.
- ☐ c. If a component functions well individually, it follows necessarily that it will function well within a specific system.
- ☐ d. Heat is transported by natural means in an active solar energy system.
- ☐ e. Convection and radiation are the only natural means of heat transfer.

ANSWERS TO ASSIGNMENT SHEET AND UNIT III TEST: SYSTEMS

Answer to Assignment 1

Three systems might be (A) the circulatory system of the human body; (B) an ecological system, such as can be seen in the life balances in small, naturally occurring pond; and (C) a motorcycle or an automobile. All are systems because they are made up of components which must function together if the entire system is to function.

- A. The components of the circulatory system are the heart and the arteries, vessels, and veins. The purpose of the system is to distribute oxygen and needed nutrients to the cells in the body. If the heart stops beating, distribution ceases. If a valve in the heart fails to close, the blood will not be pumped; if a vein or artery were to open or close, circulation of the blood could not continue.
- B. In a small pond, vegetation, insect life, and animal life function together to support life in the pond. Biological balances between these components can be very delicate. Wastes from insects and animals provide nutrients for the vegetation. The vegetation converts carbon dioxide into oxygen for the insects and small vertebrates and invertebrates. A food chain exists among these creatures and if one link of the chain is destroyed all those creatures above it may die.
- C. A motorcycle has a motor, a drive assembly, and a steering mechanism. Each of these components is also a subsystem made up of smaller components. The total mechanism is designed to transport a person from point "A" to point "B". If the motor is not functioning or if the gears do not shift out of neutral, transportation will not occur.

Answers to Unit Test 1

- a. 4
- b. 9
- c. 5
- d. 3
- e. 8
- f. 1
- g. 7
- h. 6
- i. 2

Answers to Unit Test 2

a,b

## References

AIA Research Corporation. May 1976. Solar Dwelling Design Concepts.

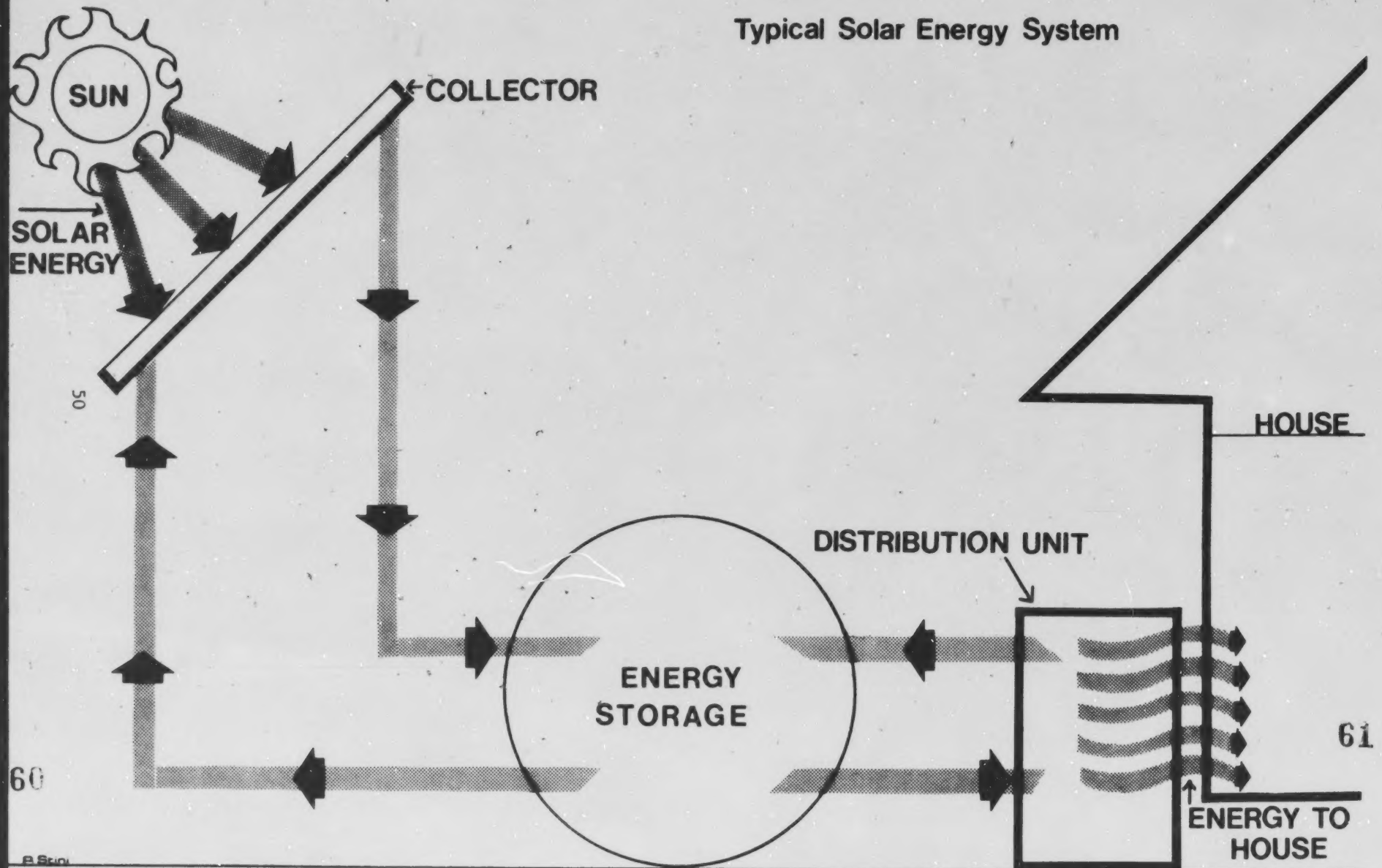
Prepared for the U.S. Department of Housing and Urban Development, Office of Policy Development, Office of Policy Development and Research. Washington, D.C.: U.S. Government Printing Office.

Balcomb, J. Douglas, James C. Hedstrom, and Hugh S. Murray. November 1976. Pacific Regional Solar Heating Handbook. Prepared for United States Energy Research and Development Administration. Los Alamos, New Mexico: Los Alamos Scientific Laboratory. Available from Superintendent of Documents, U.S. Government Printing Office.

Forrester, Jay W. 1968. Principles of Systems. Cambridge, Mass.: Wright-Allen Press, Inc.



# Typical Solar Energy System



UNIT IV  
COLLECTORS

UNIT OBJECTIVES

After completion of this unit, the student will be able to name the types of and function of the collector as a component in a solar energy system. This knowledge will be evidenced by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

Upon completion of this unit, the student will learn to

1. Associate correct definitions with the new terms in the unit.
2. Select from given statements those that accurately describe general concepts about collectors.
3.
  - A. Identify the different types of flat-plate collectors.
  - B. Select from a list the correct advantages and disadvantages associated with each type of flat-plate collector.
4.
  - A. Match terms with descriptions of concentrating collectors.
  - B. Select from a list the correct advantages and disadvantages associated with each type of concentrating collector.
5. Identify correct statements about passive collectors.

## 1. Terms and Definitions

**Beadwall** - a patented insulated window in which polystyrene beads are blown into or pulled out of a space between two sheets of glass or plastic by a vacuum-driven system.

**Clerestory window** - a south-facing window in the wall of a room which rises above an adjoining roof; the window can be used to admit solar radiation.

**Collector** - a device for receiving solar radiation and converting it to heat in a fluid.

**Concentrating collector** - a class of collectors which use reflectors to focus solar radiation on a small area.

**Fenestration** - the placement, size, and design of windows and doors in a building.

**Flat-plate collector** - a class of collectors so named because of the large surface area exposed to the sun.

**Heat-transfer medium** - a liquid or gas which absorbs heat efficiently and moves the heat away from the collector to storage or to point of use.

**Thermosyphoning** - the principle that heated gasses and liquids rise naturally has been applied as a means of heat transport in passive solar energy systems. Heat built up within a wall or roof structure can be drawn off to heat interior spaces.

**Trombwall** - a type of passive collector which makes use of a massive masonry wall, painted black and placed behind a south-facing wall of glass. Air trapped between the wall and the glass is heated, moves up over the wall and into the interior space.

## Information Sheet: Collectors \*

### 2. Introduction to Collectors

The collector can be any suitable surface which will absorb the solar radiation striking the surface (insolation), and convert it to usable thermal energy. (Note: In a photovoltaic collector, insolation is converted directly to electricity). The thermal energy captured by the collector is transferred to a fluid within the collector. This fluid, a heat-transfer medium, is usually a gas or liquid which transports the thermal energy to storage or point of use.

Specific types of collectors to be discussed are listed below. Some collectors can be organized and operated independent of the unit they serve (i.e., the building). Collectors can be classified according to whether they are used in active or passive solar energy systems. The following are usually associated with active systems:

#### A. Flat-Plate Collectors

1. Open-Water Collector
- ii. Air-Cooled Collector
- iii. Liquid-Cooled Collector

#### B. Concentrating Collectors

1. Linear Concentrating Collector
- ii. Circular Concentrating Collector

A second class of collectors can be referred to as passive collectors. Passive collectors serve as integral parts of the building unit. If a passive collector is modified, the entire design of the building would have to be modified. Some typical collectors used in passive solar systems are south-facing windows, greenhouses, skylights or clerestory windows, thermosyphoning roof or walls, and ponds (especially roof ponds).

Certain characteristics are common to all collectors. In general, a transparent sheet or plate is used to cover the absorbing surface of the collector. The absorbing surface, or absorber, is coated with a dark substance to increase absorption. Most of the solar radiation transmitted through the glass is absorbed and converted to heat. However, once heated,

\*Adapted from AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.

Percent of Possible Sunshine Intercepted by a Plane Misaligned x Degrees

| Degrees | Percent |
|---------|---------|
| 0       | 100.0   |
| 5       | 99.6    |
| 10      | 98.5    |
| 15      | 96.5    |
| 20      | 94.0    |
| 25      | 90.6    |
| 30      | 86.6    |
| 35      | 81.9    |
| 40      | 76.6    |
| 45      | 70.7    |
| 50      | 64.3    |
| 55      | 57.4    |
| 60      | 50.0    |
| 65      | 42.3    |
| 70      | 34.2    |
| 75      | 25.8    |
| 80      | 17.4    |
| 85      | 8.7     |
| 90      | 0.0     |

Table 4.1

Evidently, when orienting planes to receive sunlight, pretty close is close enough. If your angle is off as much as 25 degrees, you still are intercepting over 90% of the possible sunlight.

Source: Steve Baer, Sunspots (Albuquerque, New Mexico: Zomeworks, Inc., 1975) p. 7. Reprinted by permission of the author.



the absorber will radiate heat away from it. The purpose of the cover plate is to reduce heat loss back to the atmosphere by convection or radiation. The cover plate, usually made of glass or plastic, will trap heat radiated by the absorbing surface. While the solar radiation reaching the collector is generally in the form of ultraviolet (short-wavelength radiation), the heat radiated from the absorbing surface is characteristically long-wavelength radiation. Glass and some plastics will transmit short-wavelength radiation but absorb long-wavelength radiation. These characteristics of the materials explain why the heat is trapped in the collector.

### 3. Active Collectors

#### A. Flat-Plate Collectors

When talking about solar collectors, most people automatically think of a flat-plate collector. The flat-plate collector is simple and is widely used. It absorbs both diffuse and direct radiation. The collector can be oriented to catch the optimum insolation at a desired time and temperatures to 250°F can be obtained. These temperatures are well within the range needed for heating interior spaces or domestic hot water.

The flat-plate collector works best when the collector surface is perpendicular to the direct rays of the sun. The tilt should be determined by the season of year when the most solar radiation is needed for the solar energy system; however, the tilt need not be exact. The amount of sunshine intercepted by a misaligned collector has been calculated (see Table 4.1).

A flat-plate collector usually consists of the following: one or two cover plates; a dark-colored absorbing surface insulated on the back to reduce heat loss; and a transporting fluid, either air or gas, which absorbs the heat and carries it to storage or to points of use (see Transparency 4.1). The type of fluid used in the flat-plate collector further defines the type of flat-plate collector. Often the type of fluid used is determined by other components in the system.

i. Open-Water Collectors. Water makes a good heat transport fluid for use in a flat-plate collector. It requires a smaller space for piping, and it absorbs heat readily. In an open-collector, such as Harry Thomason has developed, the water is trickled over the absorber surface. The absorber surface is usually corrugated roofing material which is painted black. The water is distributed across the top of the collectors and trickled down the grooves where the water absorbs heat from the absorbing surface, and is then caught in a trough at the bottom and piped to storage. Without a cover, there will be heat losses by evaporation. If a glass cover is used, to prevent evaporation, water condensation on the surface can reduce the efficiency of the collector. A second cover sheet minimizes this problem.

Another possibility is to place a second sheet of the corrugated roofing over the first, leaving only a small passage for the water so that the water will be in contact with both surfaces. Open-water collectors have been operated successfully in the Washington, D.C. area. In cold climates with hard freezes, these collectors should be evaluated carefully before installation.

This type of collector can be constructed at the building site. A collector which can be constructed at the building site from easily obtained materials will be less expensive than a factory-produced collector which must be shipped intact to the site. If there comes a time when demand is sufficient to justify mass production of a standard collector type, this saving may be reduced.

ii. Hot-Liquid Collectors. Most collectors using a liquid as the heat transport medium pipe the liquid through the collector box. The pipes usually are attached to the absorber plate, and the heat transfer is by conduction. To increase heat transfer by conduction, greater absorber surface area must be in direct contact with the heat transfer medium. Rectangular pipe is used rather than round tubing, thus increasing the amount of surface contact and effecting better heat transfer. The heated liquid is transported to storage, where the heat is transferred to the storage medium.

There are problems involved in using a liquid transport medium. If water is used, freezing is a real danger: and repairs can be costly. Controls can be added to the system to prevent freezing, but the controls themselves can be costly. Also, leaks may occur. If solutions such as antifreeze are used, corrosion can decrease the efficiency of the collector. However, liquid collectors are efficient in collecting and transporting heat. The liquids used absorb heat readily and require relatively smaller space for piping than does air.

iii. Hot-Air Collectors. Air can be used as the transport medium. By using air, problems associated with freezing, leaks, and corrosion are overcome. Also, the heated air can be pumped directly into the interior space to be heated or it can be pumped to storage.

There are problems associated with using air as the transport medium. A much larger volume of air is needed to transport heat than is needed if a liquid is used as the transport medium. The transfer of heat from the absorber to air presents some problems in efficiency. Often, a finned apparatus, screenwire, or some other method is needed to increase contact of the heated surface with the air (Environmental Research Laboratory, Reprint No. 43, Tucson, Arizona: Tucson International Airport).

#### B. Concentrating Collectors

Concentrating collectors use reflectors to increase the amount of radiation striking a small area. The target area may be either a tube or a point which absorbs the thermal heat. A major problem with concentrating collectors is that they require direct radiation. Thus they will not absorb heat on a cloudy day. Also, concentrating collectors require tracking devices to follow the sun. Another problem is that the reflecting surface must be kept clean. To date, concentrating collectors have not been used extensively in systems designed for interior heating of dwellings. A major advantage of concentrating collectors is that less surface area is needed to collect solar energy in an amount equal to that collected by a flat-plate collector.

1. Linear Concentrating Collectors. Linear concentrating collectors reflect radiation onto a pipe or tube, which is the absorber. The heat-transport medium circulates through the absorber and is then moved to the point of use or to storage. Fairly accurate orientation to the sun must be maintained, both in an east-west and north-south direction. A linear concentrating collector is illustrated on Transparency 4.2.

ii. Circular Concentrating Collectors. Circular concentrating collectors are dish-shaped to focus radiation on a single point. An absorber is located on the point. The heat absorbed is carried to point of use or storage by a transport fluid. Circular concentrating collectors must track the sun to collect direct rays. However, high temperatures can be achieved which may make their use highly desirable (see Transparency 4.3).

#### 4. Passive Collectors

A passive solar energy system is designed to make the greatest possible use of natural heat transfer processes--conduction, convection, and radiation. Usually, the heat collector and the storage areas are an integral part of the living space, and it is impossible to entirely divorce the two components in a passive system. However, homes are now being built with one or several combinations of the individual components. The emphasis here will be on the collector component.

##### A. Fenestration

Windows admit into a room solar radiation which can then be absorbed by surfaces within the building. South-facing windows are used to increase heat gain. The major drawback of south-facing windows is the enormous amount of heat which is collected. To reduce over-heating, however, massive walls and floors can be used to absorb and store the heat. How massive the walls and floors must be can be calculated so that the mass does not become a drawback. If the mass is too great, it may take up too much of the heat acquired or it may take too long to warm up after periods of low temperature.

##### B. Greenhouses

Greenhouses, on the south side of a house, are also used to collect heat. However, to avoid heat loss, some kind of insulation must be available. Bead-walls are one possibility. A Beadwall is a patented system involving a space



between two sheets of glass or plastic. Polystyrene beads are blown into or pulled out of the space by a vacuum-driven system. Panels of insulating material can also be used for insulating the greenhouse to avoid heat loss at night or on cloudy days. A massive floor of rock or masonry or a masonry wall between the greenhouse and dwelling may be needed to avoid over-heating.

#### C. Skylights and Clerestory Windows

Skylights and clerestory windows can also be used to collect heat from the sun. It is important to note that both may need to be insulated at night or on cloudy days. Insulated shutters are available for this purpose. Windows placed in the ceiling or high in a wall can be a problem because the heat could be trapped near the ceiling. The heat admitted through skylights and clerestory windows will enter at a high point in the building. A return air register can be placed at a point high in the room. The heat gained from solar radiation and trapped at the ceiling can thus be circulated to floor level. A fan placed in the duct will facilitate the circulating process.

#### D. The Thermosyphoning Concept

The thermosyphoning concept, using the walls and roof, can also collect solar energy for use in heating interior spaces. The fact that hot gases or liquids rise can be used to employ a natural heat transport system. If solar-heated air, trapped in an air space within a wall or roof, is warmer than the air in the interior of the building, the solar-heated air can be drawn off through vents. If the exterior wall or roof is made of glass or plastic, much higher temperatures can be obtained and the thermosyphoning technique will be more efficient.

A special application of the thermosyphoning technique is the Trombe Wall. Placed behind a south-facing wall of glass is a massive masonry wall, painted black. An air space between the window and the wall traps the heated air, which moves up and over the wall into the room. Vents at the bottom of the wall allow colder air from the interior to enter the space, and as the air is heated it moves up and finally re-enters the interior of the house.



#### E. Roof Ponds

Roof ponds can provide both heating and cooling of buildings. The pond is usually placed on the roof. However, the pond can be put in the interior of the building with the liquid, usually water, circulated to the roof. Presently, designers are experimenting with using pools completely separated from the building to collect and store heat. Controls are needed if roof ponds are used as collectors to maintain the most comfortable temperature level within the building. By using insulated panels to either cover or uncover the pond or by filling or emptying the pond, heating and cooling needs can be satisfied.

When the ponds are on the roof, the water is usually contained in black plastic bags. Some arrangements do not use a transparent roof covering because then during the night evaporation can be used, as well as conduction and radiation, to help cool the water.

Solar ponds are most effective in warm, dry areas with cool or cold nights. In warm climates, the ponds would be covered during the day. Cooling is thus accomplished by allowing natural radiation to the sky at night. If the water is cooled at night, then during the day time, the heat from the building can be absorbed by the ponds for radiation at night. If heat is needed, the insulating panels covering the pond are removed during the day so the water can absorb heat and then placed over the pond at night to retain the solar heat collected during the day. Solar ponds are not effective in areas of the country with high humidity. High humidity interferes with night radiation during times when cooling is desired.

There are real advantages to placing the solar ponds on a flat roof. In southern climates, if the roof is flat, there is no problem about how the building is oriented with regard to the sun. In northern climates, the ponds should be covered, tilted, and placed under a transparent cover for best results. The insulation panels can be moved with the aid of fairly simple machinery and stored, perhaps over the garage or a patio covering. If the pond is in direct contact with the interior space and spread over the entire roof area of the dwelling space, heat is radiated evenly throughout the living area.

ASSIGNMENT SHEET: COLLECTORS

1. List the advantages and disadvantages of an open-water collector.

Advantages

Disadvantages

2. List the advantages and disadvantages of a hot-liquid collector.

Advantages

Disadvantages

3. List the advantages and disadvantages of a hot-air collector.

Advantages

Disadvantages

4. List the advantages and disadvantages of a linear concentrating collector.

Advantages

Disadvantages

5. List the advantages and disadvantages of a circular concentrating collector.

Advantages

Disadvantages

## ACTIVITIES--MAKING A COLLECTOR

### Activity 1

#### A. Materials Needed

1. Two cans with covers
2. Black paint
3. Four glass jars. Size is important. Each can must fit inside one jar which will in turn fit inside the second jar.
4. Thermometer

#### B. Procedure

1. Paint one can black and allow paint to dry.
2. Fill both cans with water and seal.
3. Place a can inside each of the smaller jars.
4. Lay the jars on their side where the direct rays of the sun will strike the jars.
5. After approximately 20 minutes (depending on the size of the containers) read and record the water temperature in each can.
6. Repeat the activity, but this time, place each can and jar inside the second glass container and wait for approximately 20 minutes before reading the temperature of the water.
7. Leave these "collectors" where the direct rays from the sun will strike the containers for about one hour. Read and record the temperatures again.

#### C. What Has Been Learned?

1. What temperature differences were observed?
2. How could higher temperatures have been obtained (consider using insulation and reflectors)?
3. Can you explain why a difference in temperature was observed when two glass containers were used instead of one?

## Activity 2

### A. Materials Needed

1. A 2' x 4' rectangular box with sides approximately 4" high.
2. Insulation
3. Black paint
4. Transparent glass or plastic cover
5. A large quantity of cans of the same size; beer cans or vegetable cans would be excellent.
6. Hole cutter
7. Can opener
8. Epoxy glue or caulking material
9. Thermometers

### B. Procedure

1. Make two 4 1/2 feet tubes by cutting off can lids and bottoms and gluing the cans together.
2. Remove one-half the lid and the bottom of each can. In this way, the movement of air through the tube will be impeded and more heat will be absorbed. Leave the lids at each end of the tube intact.
3. Paint the one tube black.
4. Place insulation in the bottom of the box.
5. Paint the surface of the insulation black.
6. Cut holes in either end of the box. Place cans in box so that the cans will protrude slightly at each end. Caulk around opening.
7. Cut 2-inch openings in each end of tube.
8. Place transparent cover over collector.
9. Tilt collector so that the flat, transparent surface is normal (perpendicular) to the direct rays of the sun. Be sure the holes in the tubes are not blocked.
10. After approximately 30 minutes, check the temperature of the air entering the collector at the bottom and the air escaping at the top. Be careful to shade the thermometer when taking temperature readings.

C. What Has Been Learned?

1. Is there any difference in temperature between the air rising in the tubes which were painted black and those left unpainted?
2. Materials can be a serious problem in building collectors because the materials must withstand high temperatures and prolonged exposure to solar radiation. Plastics, caulks, adhesives, and paints are of especial importance. Where might one obtain information about materials?



UNIT TEST: COLLECTORS

1. Match definitions with the correct terms.

- \_\_\_ a. Collector
- \_\_\_ b. Heat-transfer medium
- \_\_\_ c. Flat-plate collector
- \_\_\_ d. Concentrating collector
- \_\_\_ e. Clerestory window
- \_\_\_ f. Fenestration
- \_\_\_ g. Thermosyphoning
- \_\_\_ h. Beadwall
- \_\_\_ i. Trombe Wall

- 1. Placement, size, and design of windows and doors in a building.
- 2. A means of heat transport making use of the principle that heated gasses and liquids rise naturally.
- 3. A type of passive collector which uses a black masonry wall and a glass wall with an air space in between.
- 4. A component in a solar energy system which receives solar radiation and converts it to heat.
- 5. A class of collectors which expose a large surface area to the sun.
- 6. A south-facing window in the wall of a room which rises above an adjoining roof.
- 7. Polystyrene beads are blown into or pulled out of a space between two sheets of glass or plastic by a vacuum-driven system.
- 8. A liquid or gas which absorbs heat and moves it from the collector to storage or to point of use.
- 9. A class of collector which reflects radiation and focusses it on a small area.

2. Select from the statements written below those which accurately describe general concepts about collectors and mark them with an "x".

- ☐ A. Any surface which will absorb solar radiation and convert it to heat can be called a collector.
- ☐ B. If a surface is coated with a dark substance, it will increase the rate of absorption of radiation.
- ☐ C. Open-water collectors are a type of concentrating collector.
- ☐ D. The transparent sheet which covers the absorbing surface of the collector serves mainly to keep the absorbing surface clean.
- ☐ E. After radiant energy is converted to heat, it is transported away to storage or point of use in a solar energy system.
- ☐ F. Heat is trapped in the collector by the transparent covering.
- ☐ G. Once the absorbing surface of the collector has absorbed the radiant energy, there is no danger of heat loss.
- ☐ H. A south-facing window can serve as a solar collector.

### 3A. Flat-Plate Collectors

I. Identify the different types of flat-plate collectors by filling in the blanks with the proper term.

- a. Open-water collectors
- b. Hot-liquid collectors
- c. Hot-air collectors
- ☐ 1. The liquid which serves as the heat-transport medium is piped through the collector box.
- ☐ 2. Air is pumped through the collector box.
- ☐ 3. The heat-transport medium, water, is trickled over the absorber surface, which is usually made of a corrugated roofing material.

II. Select from the following list, the advantages and disadvantages associated with the three types of flat-plate collectors. Place letters from the list on the appropriate lines for each type of collector. Each letter may be used more than once.

- a. Freezing
- b. Corrosion
- c. Heat losses through evaporation if cover is not used.
- d. Leaking
- e. Heat-transfer medium can be pumped directly to point of use.
- f. Usually less expensive
- g. Water or other liquid is an efficient heat-transport fluid.
- h. If cover is used condensation may interfere with rate of absorption.
- i. Because heat transfer is a problem, greater direct contact of heat-transfer medium with absorber surface is needed.
- j. A larger volume of the heat transfer medium must be used.
- k. No problems with freezing.
- l. No problems with corrosion.
- m. No problems with leakage.
- n. A smaller piping system is needed to carry the heat-transfer medium.
- o. A larger piping system is needed to carry the heat-transfer medium.

i. Open-water collector

Advantages \_\_\_\_\_

Disadvantages \_\_\_\_\_

ii. Hot-liquid collectors

Advantages \_\_\_\_\_

Disadvantages \_\_\_\_\_

iii. Hot-air collectors

Advantages \_\_\_\_\_  
\_\_\_\_\_

Disadvantages \_\_\_\_\_  
\_\_\_\_\_

3B. Concentrating Collectors

I. Match terms with the appropriate description.

- \_\_\_\_ a. Not a collector  
\_\_\_\_ b. Linear concentrating collector  
\_\_\_\_ c. Circular concentrating collector

1. Radiation is reflected onto a pipe or tube through which the heat transport medium is circulated.
2. The radiation is focussed and reflected onto a single point.
3. Radiation is reflected onto a single spot on the moon.

II. Select from the following list the advantages and disadvantages associated with the two types of concentrating collectors. Place letters from the list on the appropriate lines for each type of collector. Each letter may be used more than once.

- a. Only a small area is needed to collect a large amount of energy.
- b. The collector must be oriented exactly with the sun.
- c. Orientation with the sun must be fairly accurate.
- d. Absorbs only direct radiation.
- e. High temperatures may be obtained.
- f. The reflecting surface must be kept clean.

1. Linear Concentrating Collector

Advantages \_\_\_\_\_  
\_\_\_\_\_

Disadvantages \_\_\_\_\_  
\_\_\_\_\_

2. Circular Concentrating Collector

Advantages. \_\_\_\_\_

Disadvantages \_\_\_\_\_

4. Passive Collectors

Identify and mark with a "T" the statements below which accurately describe passive collectors. Mark false statements with an "F".

- \_\_\_\_ a. South-facing windows collect only small amounts of heat.
- \_\_\_\_ b. There are no drawbacks to using greenhouses as passive collectors.
- \_\_\_\_ c. Because of the natural movements of heated air, air can be used as the heat-transport medium in passively heated dwellings.
- \_\_\_\_ d. Massive walls and floors of rock or masonry have no effect on the amount of heat which must be collected.
- \_\_\_\_ e. The heat admitted through skylights and clerestory windows enters at a high point in the room and is trapped there.
- \_\_\_\_ f. In a Trombe Wall, vents are placed at the top and bottom of the wall.
- \_\_\_\_ g. The purpose of the vents in the Trombe Walls is to allow warm air to enter the interior of the dwelling as it rises and to allow cooler air to be moved from the interior of the dwelling to be reheated.
- \_\_\_\_ h. Roof ponds are a type of passive solar collector.
- \_\_\_\_ i. The heat collector and the heat storage components can be entirely separated in all passive solar energy systems.
- \_\_\_\_ j. If windows are used for thermal gain, the windows must be insulated at night.
- \_\_\_\_ k. Roof ponds can only cool buildings.
- \_\_\_\_ l. Roof ponds work best in areas with high humidity.
- \_\_\_\_ m. Solar ponds may be completely separated from the building.
- \_\_\_\_ n. If a greenhouse is used to collect heat, the windows will need to be insulated at night and a massive floor or wall will be needed to absorb the heat.



ANSWERS TO ASSIGNMENT SHEETS AND UNIT IV TEST: COLLECTORS

Answers to Assignment 1

Advantages

Water is a good heat transport medium  
Collector is inexpensive  
Smaller piping system is needed to carry the heat-transport medium

Disadvantages

Without transparent cover heat is lost to evaporation.  
With transparent cover, condensation can be a problem.  
Freezing  
Corrosion  
Leakage

Answers to Assignment 2

Advantages

Water is a good heat transport medium  
Smaller piping system is needed to carry the heat transport medium

Disadvantages

Freezing  
Leaking  
Corrosion  
Heat transfer is by conduction, meaning that contact of heat transfer medium with absorber must be maximized.

Answers to Assignment 3

Advantages

Does not freeze or corrode  
Leakage is not a problem  
Air can be pumped directly to point of use.

Disadvantages

Larger volume of heat transport medium is needed.  
Requires large duct work.  
Heat transfer from absorber to air is not efficient.

Answers to Assignment 4

Advantages

Small area is needed to collect  
large amounts of energy

High temperatures may be obtained.

Disadvantages

Orientation with sun must be fairly  
accurate

Absorbs only direct radiation

The reflecting surface must be kept  
clean

Answers to Assignment 5

Advantages

Small area collects large amounts of  
energy

High temperatures may be obtained

Disadvantages

Collector must be oriented exactly  
with sun

Absorbs only direct radiation

Reflecting surface must be kept clean

Answers to Unit Test 1

- A. 4
- B. 8
- C. 5
- D. 9
- E. 6
- F. 1
- G. 2
- H. 7
- I. 3

Answers to Unit Test 2

A, B, E, F, H

Answer to Unit Test 3A

I. 1. b

2. c

3. a

- II. 1. Advantages f,g,n  
Disadvantages a,b,c,d,h  
ii. Advantages g,n  
Disadvantages a,b,d,i  
iii. Advantages e,k,l,m  
Disadvantages i,j,o

Answers to Unit Test 3B

I. 1. b

2. c

3. a

- II. 1. Advantages a,e  
Disadvantages c,d,f  
ii. Advantages a,e  
Disadvantages b,d,f

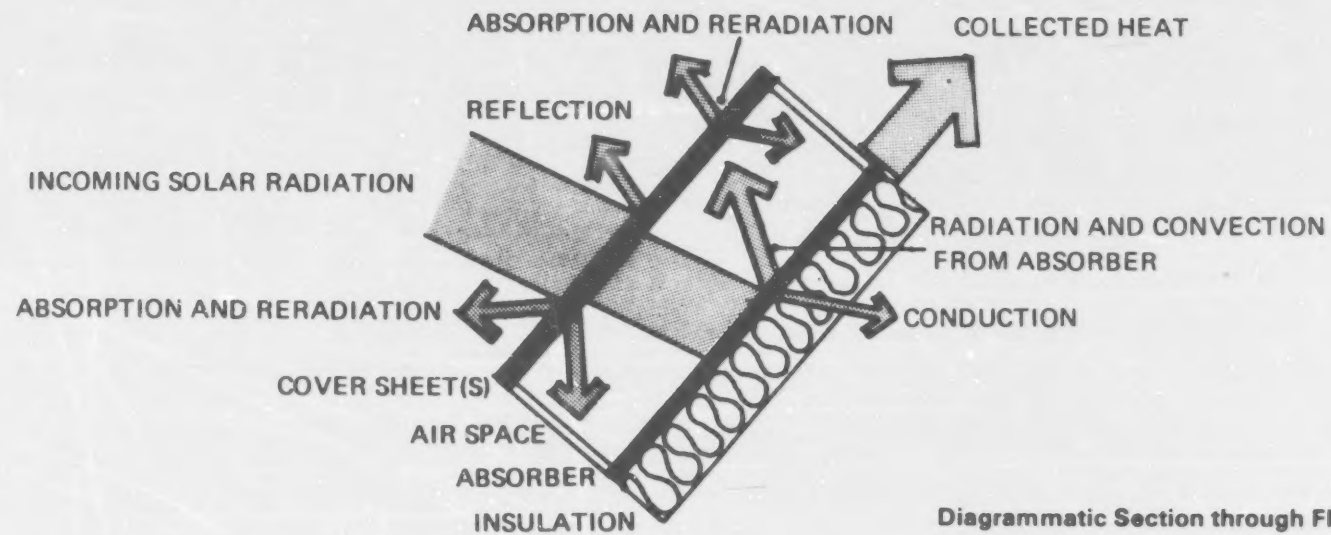
Answers to Unit Test 4

- |      |      |      |
|------|------|------|
| a. F | f. T | k. F |
| b. F | g. T | l. F |
| c. T | h. T | m. T |
| d. F | i. F | n. T |
| e. T | j. T |      |

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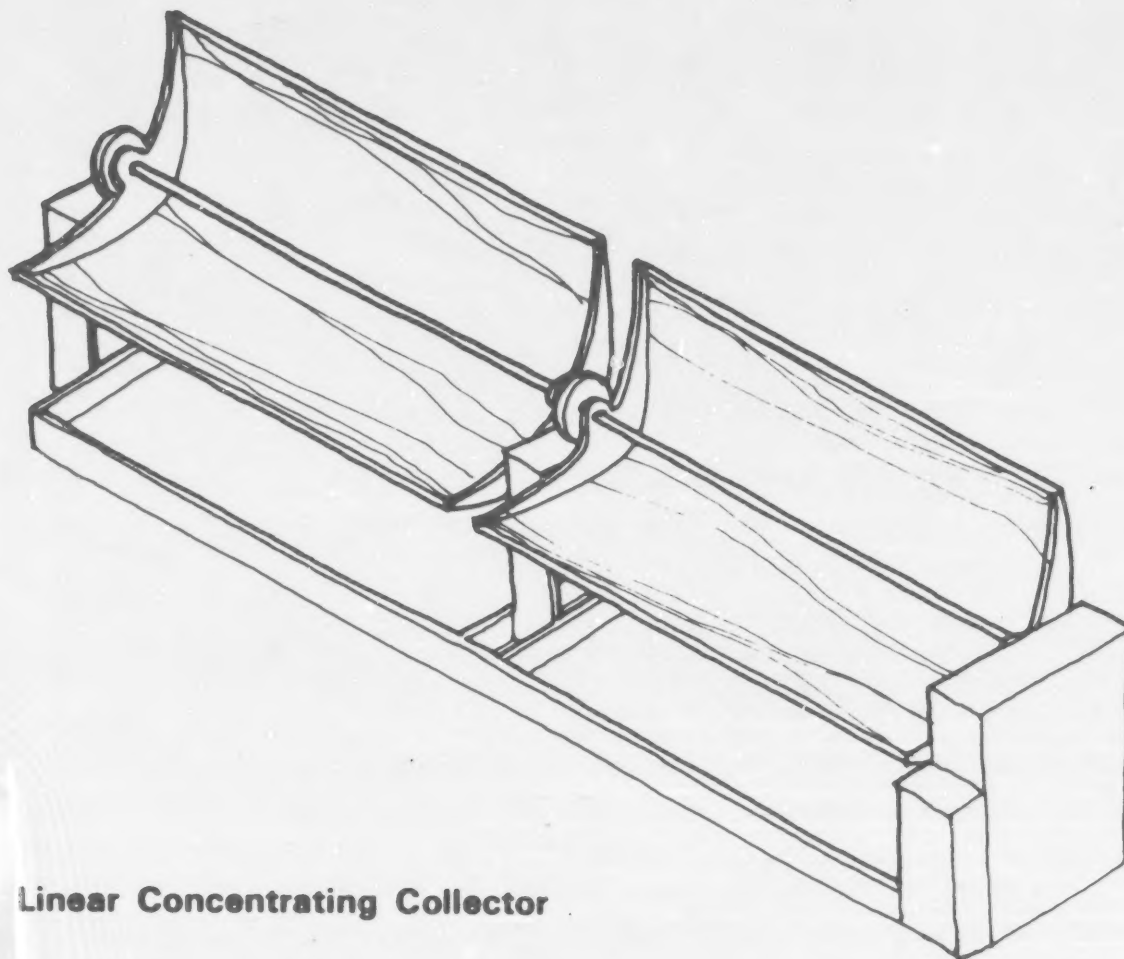
Transparency 4.1



Diagrammatic Section through Flat-Plate Collector

From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.



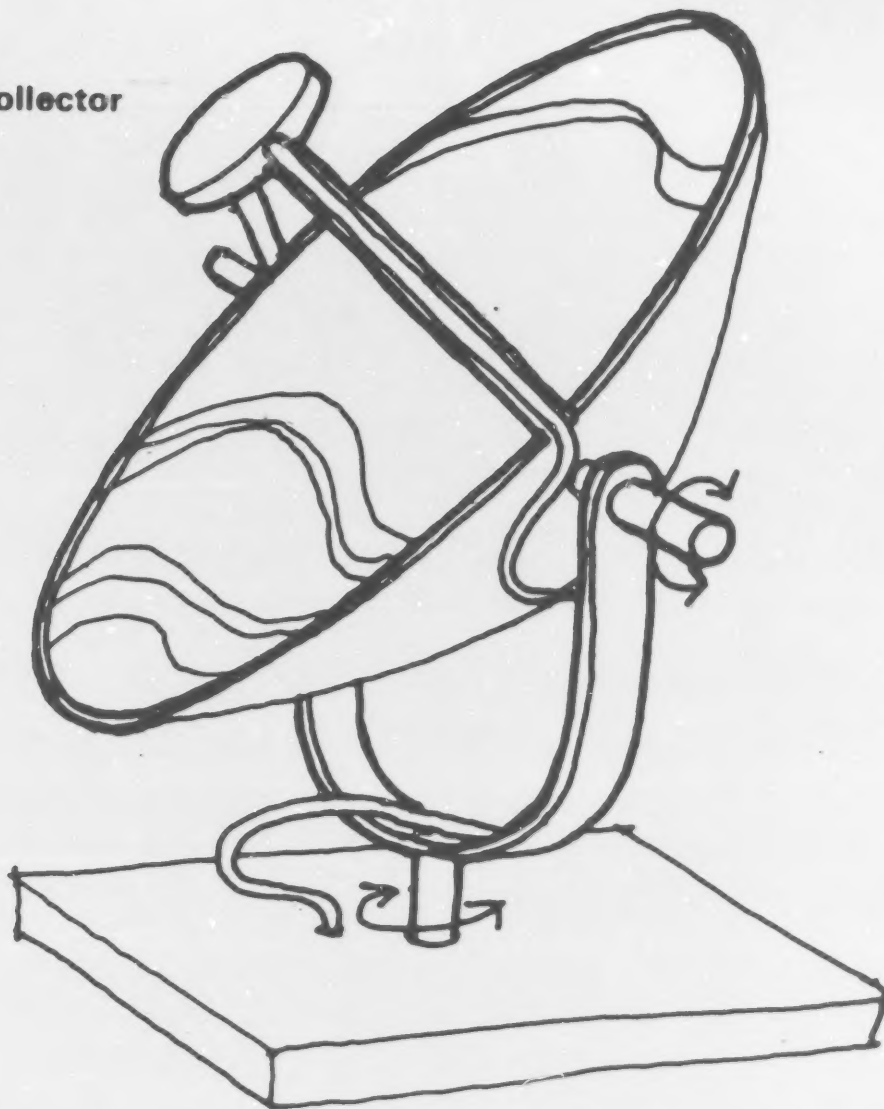


**Linear Concentrating Collector**

From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C.,  
Government Printing Office, May 1976.

Transparency 4.2

# Circular Concentrating Collector



Transparency 4.3

90

From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C.,  
Government Printing Office, May 1976.

## UNIT V

### STORAGE

#### UNIT OBJECTIVE

After completion of this unit, the student will be able to name the types of and function of the storage component of a solar energy system. This knowledge will be evidenced by scoring 85 percent on the unit test.

#### SPECIFIC OBJECTIVES

After completion of this unit, the student will learn to

1. Recognize correct statements referring to the storage component.
2. Identify which statements about passive storage are true and which are false.
3. Select from a list the correct advantages and disadvantages associated with each of three types of active storage systems.

## Information Sheet \*

### 1. The Storage Component

Energy in the form of direct or diffuse solar radiation will not be available for collection and use at night or on cloudy days. If the solar energy system is to be of value, the energy must be collected when it is available and stored for later use. The heat can be stored by raising the temperature of such substances as rocks, water, concrete, or other masonry. Another method now being investigated is to use the energy to cause changes of state, such as changing a solid to a liquid or a gas.

The type of storage used in a particular system may depend upon the type of collector used for a specific building. However, considerations about storage materials--their cost, operation, and size--must be taken into account in planning the entire solar energy system.

### 2. Heat Storage in Passive Systems

The solar radiation received from south-facing windows or transparent panels increases the temperature of room air and surfaces exposed to the sun's rays. As such, the room's air and exposed surfaces (walls, floors, furniture) are the solar storage components for a window wall, greenhouse, or transparent panel which collects the radiation. For most situations, the storage capacity of the air and surfaces will not be sufficient for long periods of heating demand. Additionally, in the process of "charging" the storage, the space may become overheated and possibly extremely uncomfortable for the occupants.

In order to reduce the overheating effect, masonry surfaces such as concrete, brick, tile, or stone on the floor or on the walls can be used for their heat storage capacity, absorbing the heat during the day and radiating it later for several hours or more. The storage effect of a particular floor or wall can be calculated as a function of the specific heat of the masonry, its volume and weight, and the expected temperature differences it will experience throughout the day. Too great a storage effect in the exposed room surfaces can have a negative effect on occupant comfort or fuel consumption if the morning "reheat" time of the materials is too

\*Adapted from AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.

long. However, properly designed, the thermal mass of construction materials can play a significant role in an integrated solar dwelling design.

To use the radiation stored in the air and room surfaces effectively, careful attention must be given to minimizing the loss of heat at night or when collection is not occurring. Insulated drapes, shutters, and other such devices are necessary to reduce heat loss and increase the use of trapped heat through windows. The room size; the window placement; the material composition, volume, and weight; and the expected temperature difference will also determine the performance of the solar storage. The exterior side of masonry walls used for thermal storage should be insulated to prevent heat loss from the walls.

A more direct application of this storage concept involves the placement of a glass or transparent wall over an exposed masonry surface, such as in the Trombe Wall. The exposed surface serves as the collector and as the heat store. The collecting surface is painted a dark color and is located directly behind the transparent surface. The heat transfer and specific heat of the wall material and the expected temperature range will determine the volume of the wall. The radiation time-lag must be accurately calculated to assure proper heating of the space. It is sometimes necessary to place insulation on the room side of the storage wall to avoid overheating the space. The exposed masonry storage method is frequently used in conjunction with interior and exterior vents to control the heat distribution to the space or to another storage system.

A variation of exposing a masonry surface to solar radiation is to expose containers filled with water. The exposed water containers may be placed just inside a glass south-facing wall. The sides of the containers facing the transparent wall are painted black and serve as collecting surfaces. To retain heat collected in this manner, moveable insulation should be used to cover the south-facing wall at night. Roof ponds function in much the same manner, collecting and storing heat during the daytime. Likewise, the water-filled containers will reradiate heat to the sky at night during the summer and thus can be used for cooling the building as well. Careful



calculations are required to properly size the storage capacity. Also, thermal controls such as interior and exterior vents may be necessary to assure a proper lag-time and to avoid overheating.

### 3. Heat Storage in Active Systems

#### Rock Storage

Rock storage is most often associated with flat-plate collectors using air as the transport medium. Pebble beds or rock piles contained in an insulated storage unit have sufficient heat capacity to provide heat for extended sunless periods. The rock storage is heated as air from the collector is forced through the rock container by a blower. Rock storage will require approximately 2 1/2 times the volume of water storage, assuming the same temperature range. For example, a rock pile with a void space of one-third the total volume can store approximately 23 Btu/cubic feet/degree F. However, rocks can be used to store heat at temperatures above 212°F.

A convenient rock size for storing solar heat is about two inches in diameter. A decrease in pebble size increases the air flow resistance through the storage and may affect blower and duct size and distribution efficiency. Rock storage does not have to be in close proximity to the collector. However, as the distance increases, the heat transfer losses between the heated air and the rocks also increases and larger air ducts and more electrical power are generally required for moving air between the collector, storage, and heated spaces.

Rock beds, while bulky, require little or no maintenance, and rock is cheap. Hot air gives up its heat quickly to the rocks, and elaborate heat exchangers such as are needed for liquid systems are not needed with air and rock.

#### Water Storage

Water has the highest heat capacity per pound of any ordinary material. It is also very inexpensive and therefore is an attractive storage and heat-transfer medium. However, it does require a large storage tank which may be expensive. It is sometimes practical to compartmentalize the storage

tank to control temperature gradients (different temperatures within the storage tank) and to maintain an efficient heat transfer. Potential disadvantages of water storage include freezing, corrosion, and leakage.

Water storage tanks must be protected from freezing if located outside the dwelling. Also, the tank must be heavily insulated to prevent loss of the stored heat. Steel tanks are subject to corrosion unless rust and corrosion inhibitors are added, but then the water cannot be used for most household purposes. A plastic liner would solve the rust and corrosion problems, but the types of plastic needed to store large quantities of water at high temperatures are expensive. Concrete is safe, durable, and relatively inexpensive; but if a leak does occur, it is difficult to repair.

Heat is generally transferred to and from storage by a working fluid circulated by an electric pump. The heated working fluid itself may be placed in storage or its heat transferred to the storage tank by a heat exchanger. The process of heat transfer to water is more efficient than to rock, and, therefore, less surface for the heat exchanger is required. However, care must be taken to guard against contamination of water intended for household use by the heated working fluid. This warning applies mainly when antifreeze or a rust inhibitor are used in the heat transport medium, for these substances may be toxic.

Systems using a liquid transport and transfer medium are better suited for use with domestic hot water heaters. Thus if the solar energy system is planned to include the use of solar energy for heating water for domestic use, a liquid system may be preferred. Also, the availability of liquid system components makes liquid systems more attractive for the time being. Although air systems were developed earlier than were the liquid systems, the latter have been used more frequently in recent years, which accounts for the availability of components for liquid systems.

#### Change-of-State Storage

Processes which induce a change of state from a solid to a liquid when heated can be used to store energy. The change in state permits the storage

of more heat per pound than if the material did not change composition. When a material such as Glauber's salt is cooled and goes from a liquid to solid state, it gives off this extra heat. This method, however, is still in the experimental state.

The great advantage of change-of-state storage is that it can contain a great amount of heat in a limited space and at limited weight. Let's say that the objective of a storage system is to hold 200,000 Btu's at 100-160° F. Water systems would need 53 cubic feet at 3,300 pounds, rocks would need 175 cubic feet at 17,500 pounds, while Glauber's salt would require only 19 cubic feet at 1,740 pounds. In addition, such salts are obtainable at relatively reasonable prices.

Salt storage, however, has a number of major limitations. The salts can only go through so many cycles before their natural state is altered to the point whereby they lose their capacity to successfully store heat. There are some chemical additions which act to prolong the number of cycles considerably, and there are some interesting experiments which, if successful, may dynamically prolong the life span.

Although salts are economical, present costs for containerization and transportation are fairly expensive. Mass production could bring these costs down dramatically.

ASSIGNMENT SHEET: STORAGE

1. A basement which is below ground and has concrete walls and floor is almost always cold. Large industrial buildings are frequently built with cement walls and concrete floors. The interior space is often very cool or even cold. Does any of the material in this unit offer an explanation as to why? If so, explain.
2. Why would it take large amounts of energy to heat the interior spaces described above?
3. List the advantages and disadvantages of using rock storage.
4. List the advantages and disadvantages of using water storage.

## ACTIVITIES--STORAGE

### A. Materials Needed

1. A large, well-insulated ice chest (lid off)
2. A clear cover
3. Two thermometers
4. Props for supporting the chest at the latitude angle
5. Five-gallon can painted black, with rubber gasket in screw-top lid
6. Wire
7. Graph paper

### B. Procedure

1. Place the chest on the standards with the long axis of the chest pointing east-west and the open top facing south.
2. Using the standards to support the box, tilt the box south at an angle equal to the latitude.
3. Fill the 5-gallon can with water. Be sure the rubber gasket, which can be cut from an inner tube, is flat and in place. Slip the thermometer into a wire holder attached at the back of the 5-gallon can, and place the can in the chest with the thermometer at the top back of the can, i.e., out of the sun. Orient the thermometer so that readings can be taken without uncovering the box.
4. Slip the vinyl cover over the chest--some wire or string or tape should be wrapped around the cover to keep it from blowing off.
5. Hang the air thermometer from a wire at the back of the case, again, out of the sun--in the shadow of the chest.
- 6a. Read the thermometers every 2 hours throughout a 24-hour period, and record the readings for each thermometer.
- b. Read the thermometers at 8:00 a.m. and 8:00 p.m. for 7 consecutive days.
7. Plot the temperature readings for both thermometers over the 24-hour period.

### C. What Has Been Learned?

The sun heats the water, but the water loses heat to the surroundings. The water temperature rises on sunny days. The temperature falls during the night



or during cloudy weather. On some cloudy days when the clouds are thin and and the sky is bright, the temperature may stay even or rise slightly.

The box does not measure the sunshine or the cold very accurately but it does show the difference and this is what is important to a solar-heated house.

The box is not a model of a solar-heated house. The temperature fluctuates much more in the box than in a house.

1. What differences are there in the temperature readings for the two thermometers?
2. Does the temperature inside the box fluctuate more or less than the temperature outside the box?
3. How do the fluctuations in the two temperature readings relate to each other?

UNIT TEST: STORAGE

1. Check correct statements referring to the storage component with an X.
  - ☐ a. If a solar energy system is to be of value, the energy which is collected must be available for later use.
  - ☐ b. Heat can be stored in water, rocks, and concrete, among other possible materials.
  - ☐ c. Changing a solid to a liquid does not involve the use of energy.
  - ☐ d. The type of collector used has no effect on storage.
2. Mark with a "T" those statements about passive storage which are true, and identify with "F" those statements which are false.
  - ☐ a. When south-facing windows are used as the collectors, the best storage is the air itself and the furniture and walls.
  - ☐ b. To reduce overheating, masonry and concrete walls and floors can be used to store heat.
  - ☐ c. Overheating is not a problem in a passive system using south-facing windows to collect heat.
  - ☐ d. If the mass of concrete and masonry is too great, fuel consumption from an auxiliary heating system may go up.
  - ☐ e. The performance of solar storage in passive systems can be optimized by proper calculation of the storage mass needed.
  - ☐ f. It's impossible to calculate the storage effect of exposed room surfaces in passive storage.
  - ☐ g. Passive solar energy systems require that there be no windows in the dwelling.
  - ☐ h. If exterior masonry walls are used for their heat storage capacity, the internal surface must be well insulated.
  - ☐ i. Water can be used as the storage component in a passive energy system.
  - ☐ j. Water storage is effective for heating and cooling a dwelling.

3. Select from the following list the advantages and disadvantages associated with the three types of active storage. Place numbers from the list on the appropriate lines for each type of storage arrangement. Each number may be used more than once.

1. Contains a great amount of heat in a limited space and at a limited weight.
2. Since it is most frequently used, components are readily available.
3. After extended use, the storage capacity is lost.
4. Freezing is a problem.
5. Freezing is not a problem.
6. Corrosion is a problem.
7. Corrosion is not a problem.
8. Leakage is a problem.
9. Leakage is not a problem.
10. Finding an effective storage container is a problem.
11. Container is not a problem.
12. It can store heat at high temperatures.
13. The storage medium is bulky.
14. It has a high heat capacity per pound.
15. Weight is a problem.
16. Maintenance is high.
17. Maintenance is low.
18. It is still in the experimental stages.
19. The medium is inexpensive.
20. Heating of domestic water is easily integrated into the system.

A. Rock Storage

Advantages \_\_\_\_\_

Disadvantages \_\_\_\_\_

B. Water Storage

Advantages \_\_\_\_\_

\_\_\_\_\_

Disadvantages \_\_\_\_\_  
\_\_\_\_\_

C. Change-of-State Storage

Advantages \_\_\_\_\_  
\_\_\_\_\_

Disadvantages \_\_\_\_\_  
\_\_\_\_\_

## ANSWERS TO ASSIGNMENT SHEET AND UNIT TEST V: STORAGE

### Answer to Assignment 1

Masonry surfaces and concrete absorb whatever heat is available. In a basement there is no insulation between the wall and the ground, and the heat will move out into the surrounding dirt and thus not be available to reheat the interior space. The mass of the concrete and masonry in an industrial building may be so great that heat cannot be supplied in a sufficient quantity. The heat provided, rather than heating the air, is absorbed by the masonry and concrete.

### Answer to Assignment 2

It would take large amounts of energy to heat the interior spaces which are enclosed by cement and masonry because the available heat will be absorbed by these surfaces.

### Answer to Assignment 3

#### Rock Storage

##### Advantages

Large heat capacity  
Can store heat at high temperatures  
Low maintenance  
No leakage  
Inexpensive  
Used with air, exchange is simple

##### Disadvantages

Bulkiness of the rocks  
Heaviness of the rocks  
Require large space

### Answer to Assignment 4

#### Water

##### Advantages

Highest heat capacity per pound  
Water is inexpensive  
Heat transfer to water is more efficient than to rock  
Heating of domestic water is easily integrated

##### Disadvantages

Storage tanks are expensive  
Freezing  
Corrosion  
Leakage



Answers to Unit Test 1

a, b

Answers to Unit Test 2

- a. F
- b. T
- c. F
- d. T
- e. T
- f. F
- g. F
- h. F
- i. T
- j. T

Answers to Unit Test 3

- A. Advantages 5, 7, 9, 11, 12, 17, 19  
Disadvantages 13, 15
- B. Advantages 2, 14, 19, 20  
Disadvantages 4, 6, 8, 10, 15, 16
- C. Advantages 1, 5<sup>\*</sup>  
Disadvantages 3, 6<sup>\*</sup>, 8<sup>\*</sup>, 10, 18

\* Answer may be omitted.

## References

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UNIT VI  
DISTRIBUTION

UNIT OBJECTIVE

After completion of this unit, the student will be able to explain the methods available for transporting the thermal energy to the point of use. This knowledge will be evidenced by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student will learn to

1. Recognize correct statements referring to the distribution component.
2. Identify correct statements about distribution processes which make use of the flow of gasses.
3. Identify correct statements about distribution processes which make use of radiation.

1. The Distribution Component

Generally speaking, methods by which thermal energy from storage or collector can be distributed to point of use are gas flow and radiation. Within each category there are several techniques by which the distribution of energy to occupied spaces can be accomplished. Some involve mechanical and electrical equipment and processes while others utilize natural convection and radiation. The manner in which solar radiation is collected and stored will usually determine the means of distribution. For example, in a flat-plate collector which employs air as the heat-transport medium and a rock pile to store the heat, distribution is usually accomplished by air.

2. Gas Flow Distribution

Natural Convection

Natural convection is the circulatory motion of air caused by thermal gradients without the assistance of mechanical devices. An example of convection is the motion of smoke towards room lamps--the hot air generated by the lamp rises because it is less dense, and cooler air moves in to replace it.

Natural convection is a useful means of distributing solar thermal energy because it requires no mechanical or electrical input. However, for this same reason, careful attention to design is required to maintain proper control of convective distribution methods. The placement of solar collectors, storage, interior and exterior walls and openings is extremely important for the successful operation of convective distribution.

The operation cycle of natural convective distribution is quite simple. Heat from the collector or storage is supplied to the living space. This process is controlled by the collector or storage design or by wall or floor vents. As the hot air rises to displace cooler air, convection currents similar to those causing winds occur, and the air is distributed through the

\* Adapted from AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C.: Government Printing Office, May 1976, pp. 30-31.

space. The air is cooled, becomes dense, and falls toward the floor, where it is captured by cool air return vents, passed through the collector and storage and once again distributed. The cycle will continue as long as there is a temperature difference between the collector/storage components and the room air. When the convection heating cycle is not desired, in the summer for instance, the warmer air may be vented to the exterior.

#### Forced Air

A forced air system relies on mechanical equipment and electrical energy for the distribution of thermal energy. Design for solar systems is much the same as for conventional forced air systems. However, because solar-produced temperatures in storage are often relatively low, distribution ducts and vents must be larger than those used in conventional heating/cooling systems. Therefore, to achieve maximum efficiency in a solar system, careful attention to the design of air distribution throughout a dwelling is required.

Forced air distribution for solar systems is similar to conventional air distribution. Air from either the collector or storage is blown through ducts to the occupied spaces. The type of solar collector or storage is not the determining factor for selection of a forced air ducted system: the system is adaptable to rock, water, or change-of-state storage components. For rock and containerized change-of-state storage, air is simply blown through the storage to ducts which supply the dwelling spaces. In the case of water storage, a heat exchanger is required to transfer heat from the liquid to air, which is distributed to dwelling spaces.

### 3. Radiation

#### Natural Radiation

Radiation occurs as a natural phenomenon. It is the direct emission of energy by a radiation source, and occurs without the need for any intervening substance such as air or water. All of the energy from the sun reaches the



earth by radiation through space. Thus, radiation can take place without the assistance of mechanical devices. The radiation properties of the emitting and absorbing surfaces, which are influenced by their temperature, will determine the rate of heat flow between the two surfaces.

Unlike natural convection, which is dependent on differential air temperatures for distribution, natural radiation is dependent on differential surface temperatures. An example of natural radiation is the sun warming a greenhouse on a cold day. The radiant energy is transferred directly to the greenhouse surfaces and is not significantly affected by the cool temperature of the surrounding air. Natural radiation is particularly useful for collector or storage systems which are directly exposed to the occupied spaces. The captured energy can be emitted by natural radiation directly to the room's surface. The walls, floors, and ceiling of a dwelling are used to collect and/or store thermal radiation. The energy will radiate directly to a room's other cooler surfaces.

#### Forced Radiation

Forced radiant distribution relies on the transfer of heat to air in the occupied spaces by radiation and convection from circulating hot water liquid flow through tubes. For cooling, the forced radiant system is generally used in conjunction with a refrigeration unit which passes chilled water through a fan coil unit located at the point of distribution. A blower is used to force air through the cooled fan coil unit and into occupied spaces.

The piping for the radiant system may be located in the ceiling, floor, or along the wall in fin tube baseboard units. The only significant alteration required of conventional radiant systems for use by solar systems is the enlargement of the radiations surfaces--larger fin tubes or closer spaced ceiling or floor coils--because of lower temperatures from storage.

UNIT TEST: DISTRIBUTION

1. Mark with a "T" those statements which are true, and identify with "F" those statements which are not true.

- ☐ A. There are four general methods used for distributing the thermal energy from storage or the collecting surface to the point of use.
- ☐ B. Pumps must always be used to force a heated liquid or air through the distribution system in solar heating systems.
- ☐ C. The heat transfer medium may determine the type of distribution system used.
- ☐ D. The way in which solar radiation is collected and stored may determine how the thermal energy is distributed.
- ☐ E. Radiation is the only method for distributing thermal energy.
- ☐ F. Natural methods for distributing thermal energy are convection and radiation.
- ☐ G. The distribution component of a solar energy system can be accomplished by using mechanical equipment and processes.
- ☐ H. Natural heat transfer principles cannot be applied in distributing thermal energy to a house.

2. Indicate which of the following statements apply to natural convection and which apply to forced air. Not all statements may apply.

A. Natural Convection \_\_\_\_\_

B. Forced Air \_\_\_\_\_

- 1. The two surfaces must be in direct physical contact for heat transfer to occur.
- 2. When the heating cycle is not desired, the warm air can be vented to the exterior of the building.

3. Distribution is similar to that used in conventional heating systems.
  4. No mechanical or electrical input is required if the distribution system is designed carefully.
  5. Distribution is controlled by the collector or storage design or by wall or floor vents.
  6. Vents and ducts must be much larger than in conventional systems because temperatures are relatively low.
  7. The system is adaptable to any kind of storage component.
  8. Distribution will occur only if the sun is not shining directly on the surface.
  9. Distribution will continue as long as there is a difference in temperature between the collector/storage components and the room air.
3. Indicate which statements below refer to Forced Radiation (FR) and which refer to Natural Radiation (NR). Some statements may refer to both; some may refer to neither method of distribution.
- ☐ A. Radiating surfaces, such as fin tubes or ceiling or floor coils, must be larger than in conventional systems.
  - ☐ B. The walls, floors, and ceiling may be used not only to collect and store the energy but also in the distribution of the energy.
  - ☐ C. Heat flow is determined by differences in temperature of two surfaces.
  - ☐ D. Hot water is circulated through tubes in the floor or ceiling.
  - ☐ E. Heat flow is partially aided by air temperature differentials.

ANSWERS TO UNIT TEST VI: DISTRIBUTION

Answers to Unit Test 1

- A. F
- B. F
- C. T
- D. T
- E. F
- F. T
- G. T
- H. F

Answers to Unit Test 2

- A. Natural Convection 2, 4, 5, 9
- B. Forced Air 3, 6, 7

Answers to Unit Test 3

- A. FR
- B. NR
- C. FR, NR
- D. FR
- E. FR

UNIT VII  
REPRESENTATIVE SOLAR ENERGY SYSTEMS  
FOR HEATING HOMES

UNIT OBJECTIVE

After completion of this unit, the student will be able to describe some representative solar energy systems. This knowledge will be evidenced by scoring 85 percent on the unit test.

SPECIFIC OBJECTIVES

After completion of this unit, the student will learn to

1. Associate correct definitions with the new terms in the unit.
2. A. Name and describe the components of a warm-air flat-plate system.  
B. Identify advantages and disadvantages of the system.
3. A. Name and describe the components of a warm-air flat-plate system.  
B. Identify advantages and disadvantages of the system.
4. A. Name and describe the components of a warm-water concentrating system.  
B. Identify advantages and disadvantages of the system.
5. A. Name and describe the components of a warm-air passive system.  
B. Identify advantages and disadvantages of the system.



1. Terms and Definitions

Auxiliary energy system - in addition to the solar energy system, an additional heating system may be installed. These additional systems can range in complexity from an air-tight, woodburning stove to a gas-fired furnace.

Heat transfer medium, or heat transport fluid - a liquid or gas which absorbs heat efficiently and moves the heat away from the collector to storage or to point of use.

## 2. Warm-Water Flat-Plate System

Solar heating using water as the heat transfer and storage medium is a system which is in common use today. The basic components of a typical water system consist of a collector; storage; a system of piping, pumps, and controls for circulating water from storage through the collector; and a distribution network for transferring stored heat to the dwelling space. The relationship of the various components of a warm-water solar system is diagrammed in Transparency 7.1.

### Component Description and Operation

A. Collector. The liquid-cooled flat-plate collector has a flat absorbing surface integrated with transfer fluid piping which collects both direct and diffuse radiation. Energy is removed from the collector by a liquid flowing through conduits in the absorber plate. The transport fluid is pumped to storage, where the heat is transferred to the storage medium (water in this case) and then returned to the collector to absorb more heat. Generally, the transfer fluid is circulated through the collector only when the absorbing surface is hotter than storage (except in instances when snow has covered the collector surface and the heated transport fluid is circulated through the collector to melt it).

B. Storage. Storage consists of either a concrete or a steel tank located near or beneath the building (access should be provided). The tank should be insulated to minimize heat loss. A concrete tank should be lined with a leak-proof material capable of withstanding high storage temperatures for extended periods without deterioration. Heat from the collector is transferred to storage by a heat exchange coil passing through the storage tank. Coil length and size is dependent on expected collector operating temperatures.

\* Excerpt from AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976, pp. 32-38.

C. Distribution. The distribution system consists of a pump and pipes which deliver heated water to the occupied spaces. A thermostat controls the operation of water flow or fan coil unit use in each room or dwelling. Baseboard heaters (convectors) require careful evaluation when not used in conjunction with a fan coil unit. Liquid-cooled flat-plate collectors seldom deliver water above 150°F in winter operation without auxiliary energy or reflected surface focusing. For this reason most warm water distribution systems use fan coil units or enlarged convectors.

Energy is transported away from the collector to storage by water or a water-antifreeze solution. Liquid transport fluids should be carefully evaluated before selection. The liquid must absorb heat readily at various collector temperatures and easily give up heat to the storage medium. Additionally, the liquid should not be corrosive to the system components, toxic, or susceptible to freezing or boiling.

A gas-fired conventional boiler is integrated with the solar system to provide an auxiliary energy supply should the solar system fail to function or not meet the dwelling's heating requirement. The distribution piping is run through the boiler where an energy boost may be supplied when temperatures from storage are not sufficient to heat the dwelling adequately.

Domestic hot water piping is run through the central storage tank prior to passing through a conventional water heater. Storage heat is transferred to the hot water piping, thereby either eliminating the need for additional heating or substantially reducing the energy required to raise the water to the needed distribution temperature. The domestic water heating system may operate independent of the space heating system. This is very useful for summer months when space heating is not required.

#### Advantages of Warm-Water Flat-Plate Systems

1. They have repeatedly been proved to work well.
2. Water is a cheap and efficient heat transfer and storage medium.
3. Piping, as opposed to ductwork, uses little floor space, is easily interconnected, and can be routed easily to remote places and around corners.

4. The circulation of water uses less energy than the circulation of air with corresponding heat content.
5. Much less heat exchanger area is required than with an air system.

#### Disadvantages of Warm-Water Flat-Plate Systems

1. High initial cost, particularly when expensive prefabricated collectors are employed. With the use of large areas of lower-efficiency collectors, the total system cost may be lowered considerably.
2. Care must be taken to prevent the occurrence of corrosion, scale, or freeze-up capable of causing damage or blockage.
3. Leakage anywhere in the system can cause a considerable amount of damage to the system and to the dwelling.
4. Contamination to the domestic hot water supply is possible if a leak allows treated water storage to enter the domestic water system.

### 3. Warm-Air Flat-Plate System

Warm-air systems differ from warm-water systems in that air is used to transfer heat from collector to storage. The storage medium can be water, but typically rock piles are used for warm-air systems. Heat, stored in the rock pile, can easily be distributed to the dwelling space by a forced air system. One possible arrangement of a warm-air system is diagrammed in Transparency 7.2.

#### Component Description and Operation

A. Collector. The-air cooled flat plate collector has a solid absorbing surface and collects both direct and diffuse radiation. Energy is removed from the collector by air flowing in ducts beneath the absorber plate. As shown in the diagram, the system may be operated in four different modes:

1. heating storage form collector
2. heating house from collector
3. heating house from storage
4. heating house from auxiliary energy system

The four modes of operation are regulated by several sets of dampers. One set of dampers will direct air flow from the collector into storage or directly into the occupied spaces while another set will regulate air flow from storage to the occupied spaces. The dampers may be adjusted by manual



or automatic controls. During modes two and three, an energy boost may be supplied to the warm air by the auxiliary energy system before the air is distributed to the occupied space. The amount of the energy boost is determined by the temperature of the air passing through the auxiliary heater and the amount of heat required at the point of use.

B. Storage. Storage consists of rocks about two inches in diameter, contained in a concrete bin in a basement area or underground beneath the building. The container is insulated on the earth sides to reduce heat loss. The storage capacity should be sufficient to provide several days of winter heating.

Because the temperatures in rock storage are typically highly stratified from inlet to outlet, the air flow providing heat to storage should be from top to bottom. This insures that the temperature of air returning to the collector from the storage is as low as possible, thereby increasing collector efficiency. The air flow, when removing heat from storage, should be in the opposite direction to insure that air returning to the rooms is as warm as possible.

C. Distribution. The hot air distributed to the rooms comes either directly from the collectors or from storage. The ducting required to conduct the air from the collectors to storage is extensive when compared to analogous piping requirements for liquid-cooled collectors. Two blowers are required to distribute air throughout the system.

Almost any type of auxiliary energy system can be used in conjunction with a solar system. The auxiliary system may be completely separate or fully integrated with the solar heating/cooling system. However, in most cases it makes economic sense to integrate the back-up system with the solar system. This may mean running the distribution component from heat storage to the occupied space through the auxiliary system where an energy boost may be supplied when storage temperatures are low. Heat from storage may be used in conjunction with a heat pump. The heat pump, a device which transfers heat from one temperature level to another by means of an electrically driven compressor, utilizes the solar heat available from storage to supply necessary



heat to the occupied space. The advantage of the heat pump/solar system integration is the reduction of electrical energy required by the heat pump because of heat supplied by solar storage. Also, the heat pump is the most efficient device presently available for extracting and transferring electricity into heat.

Piping for the domestic hot water is run through the rock pile storage bin. As a result the domestic hot water is preheated before passing through a conventional water heater, thus reducing the water heater's energy requirement.

#### Advantages of Warm-Air Flat-Plate Systems

1. Capital cost tends to be lower than a water system of the same capacity.
2. There is no problem with corrosion, rust, clogging or freezing.
3. Air leakage does not have the severe consequences of water leakage.
4. Domestic hot water supply is not subject to contamination by leakage from heat storage, as in the water system.

#### Disadvantages of Warm-Air Flat-Plate Systems

1. Ductwork risers occupy usable floor space and must be aligned from floor to floor.
2. Air, having a lower thermal storage capacity than water, requires correspondingly more energy to transfer a given amount of heat from collector to storage, and from storage to occupied spaces.
3. Air collectors and storage may need frequent cleaning to remove deposits of dust (filters may solve this problem).
4. Air systems require a much larger heat exchange surface than liquid systems.

#### 4. Warm-Water Concentrating System

Solar systems with concentrating collectors have not been extensively used for the provision of space heating or cooling. The absence of such equipment from the market is one major reason. In addition the high cost and uncertain reliability of tracking or concentrating equipment in adverse

weather conditions has been another primary reason for the limited use of concentrating systems. However, they do offer advantages over flat-plate collectors--primarily the generation of high temperatures to operate heat driven cooling systems.

Representative solar system three utilizes a linear concentrating collector. The system is diagrammed in Transparency 7.3.

#### Component Description and Operation

A. Collector. The collector is a linear concentrator with a glass-enclosed pipe absorber. The collector captures only direct radiation and is, therefore, limited to climatic regions with considerable sunshine and direct radiation in winter. However, where applicable the linear concentrating collector offers considerable economies over flat-plate collectors since the necessary absorber area is reduced and the assembly is often simpler to construct.

The absorber pipe is a black metal tube within a glass enclosure under vacuum to reduce convection and radiation losses. Radiation is focused on the absorber by a trough-shaped reflector surrounding the pipe.

B. Storage. Storage consists of a steel tank or a lined concrete block enclosure filled with water. Again, the storage unit should be insulated to minimize heat loss. As with most all solar storage techniques, special structural support will be required if the storage tank is to be located in the dwelling.

C. Distribution. The distribution system is by heated water to baseboard convectors. Heat is removed from storage by liquid-to-liquid heat exchanger. The heated water is pumped to baseboard convectors located throughout the building. If storage is below a preset minimum temperature, the pump continues to operate with a conventional oil or gas-fired furnace assist in the liquid distribution.

As shown in the system diagram, collector fluid transport is by means of a pump which causes the fluid to flow through the absorber and into the

storage heat exchanger, from which energy is removed and transferred to storage. The working fluid should be a heat transfer medium which has excellent transport properties and a boiling point above the expected operating temperature of the collector.

Domestic hot water piping is run through a heat exchanger in storage, thus preheating the water, before it proceeds to a conventional water heater which also provides storage. The water heater may or may not supply a boost to the water depending on its temperature.

#### Advantages of Warm-Water Concentrating Systems

1. Potential for more than double the temperatures of either air or water flat-plate collectors (particularly useful for solar cooling).
2. Total absorber area needed is substantially smaller than flat-plate collectors.
3. Collector forms lend themselves to mass production techniques.
4. Water requires less piping and storage space than air.
5. Water is a cheap and efficient heat transfer and storage medium.

#### Disadvantages of Warm-Water Concentrating Systems

1. Capital cost of collectors at present is greater than either air or water flat-plate collectors.
2. Concentrating collectors may present problems of operation, reflecting surface durability, and structural mounting.
3. Leakage at flexible absorber connections may present possible problems.
4. Climatic applicability for winter space heating is limited because only direct radiation can be collected.

#### 5. Warm-Air Passive System

The passive system described here is one possible concept among many. It makes use of extensive south-facing glazing with an intermediate collection/storage wall between the glazing and the occupied space. It relies in part on thermosyphoning. Diagrammatically, the passive system can be represented as illustrated in Transparency 7.4.

### Component Description and Operation

A. Collector. The passive collector, made up of a massive south-facing wall of either concrete or masonry separated by an air space from an outer wall of glass, captures direct, diffuse, and reflected solar radiation. With the use of automatic or manually operated dampers and vents, the system may operate in four modes.

1. natural ventilation--no collection
2. house heating from collector
3. storage heating from collector
4. house heating from collector and storage

When no collection or heat distribution is required, the vents and dampers may be opened to provide natural ventilation and removal of heat striking the collector. The space may be heated directly from the collector by closing the storage vent duct, thus forcing the heated air into the occupied space. Once sufficient heat has been transferred to the space, the storage vent may be opened and heated air from the collector transmitted to storage. If heat is required at a later time, the storage vent may be opened to allow stored heat to enter the occupied space.

B. Storage. The system employs several storage concepts. The exposed masonry wall which the radiation strikes acts as a storage element. The warmed masonry surface transmits collected heat to the occupied space by radiation. The second storage element is a rock pile located beneath the occupied space. Insulation is placed between the rock pile and floor surface to avoid overheating the space. Water or containerized salts (change-of-state storage) could also have been used as the storage medium.

C. Distribution. Heat is distributed to the occupied spaces from the collector or storage component. Ducting is required to transport the heated air from the collector to storage, and a small fan may be necessary to circulate this air. Heat is distributed to the space by convection from the collector and/or storage, by radiation from the collector and surrounding surfaces, and to a small degree, by conduction from the collector and surrounding surfaces.



Domestic water heating is not directly integrated in the solar space heating system. However, a storage tank or the domestic hot water piping may be placed in the rock pile storage to preheat the water before it passes through a conventional electric or gas water heater.

#### Advantages of Warm-Air Passive Systems

1. A system with electrical controls can be designed to operate manually in a power failure.
2. Cost should be reduced through simpler technology and elimination of a separate collector.
3. Collector serves multiple functions (i.e., can be a wall or roof).

#### Disadvantages of Warm-Air Passive Systems

1. May not be cost effective relative to warm air or water flat-plate collector systems.
2. In many cases, require automatic or manual insulating devices which are expensive and may require life style modification.
3. Larger unobstructed area needed to the south of the house for a vertical passive collector than for a roof collector.
4. In some climates and for some passive systems, low winter sun angles may be disturbing to the occupants.
5. Potential problems of occupant-privacy for passive systems with large expanses of south-facing glass.
6. Potentially large nighttime thermal losses from collector if not properly insulated.



# ACTIVITIES--REPRESENTATIVE SOLAR ENERGY SYSTEMS FOR HEATING HOMES

## Activity 1

- A. From the matrix below, choose components and a heat transport fluid for a hypothetical active solar energy system. Anticipate possible advantages or disadvantages which might be associated with the system. Consider some systems which were not discussed in the information section of this unit.

|                                                          |                                     | <u>Heat Transfer Fluid</u> |        |
|----------------------------------------------------------|-------------------------------------|----------------------------|--------|
| Components                                               |                                     | Air                        | Liquid |
| C<br>o<br>l<br>l<br>e<br>c<br>t<br>o<br>r<br>s           | Air                                 |                            |        |
|                                                          | Flat-Plate    Open H <sub>2</sub> O |                            |        |
|                                                          | Liquid                              |                            |        |
| S<br>t<br>o<br>r<br>a<br>g<br>e                          | Concentrating    Linear             |                            |        |
|                                                          | Circular                            |                            |        |
|                                                          |                                     |                            |        |
| D<br>i<br>s<br>t<br>r<br>i<br>b<br>u<br>t<br>i<br>o<br>n | Water                               |                            |        |
|                                                          | Rock                                |                            |        |
|                                                          | Change-of-State                     |                            |        |
|                                                          | Forced Liquid<br>(Radiation)        |                            |        |
|                                                          | Forced Air                          |                            |        |
|                                                          |                                     |                            |        |

- B. A system is defined as a group of components forming a unified whole. In performing step A, above, did you find that choosing one component restricted your choice of the other components? In your own words, explain why your choice might become more restricted as each component is added.

### Activity 2

A similar matrix for components of a passive system are shown below.

| Components                                               |                      | <u>Heat Transfer Medium</u> |       |
|----------------------------------------------------------|----------------------|-----------------------------|-------|
|                                                          |                      | Air                         | Fluid |
| C<br>o<br>l<br>l<br>e<br>c<br>t<br>o<br>r                | South-facing Windows |                             |       |
|                                                          | Clerestory Windows   |                             |       |
|                                                          | Trombe Wall          |                             |       |
|                                                          | Water Ponds          |                             |       |
|                                                          | Greenhouse           |                             |       |
| S<br>t<br>o<br>r<br>a<br>g<br>e                          | Floor                |                             |       |
|                                                          | Walls                |                             |       |
|                                                          | Water Ponds          |                             |       |
| D<br>i<br>s<br>t<br>r<br>i<br>b<br>u<br>t<br>i<br>o<br>n | Convection           |                             |       |
|                                                          | Radiation            |                             |       |
|                                                          | Conduction           |                             |       |

Why cannot this matrix be used in a manner similar to the matrix in Activity 1?

UNIT TEST: REPRESENTATIVE SOLAR ENERGY SYSTEMS

1. Match terms with the correct definitions

- |                                |                                                                                              |
|--------------------------------|----------------------------------------------------------------------------------------------|
| ___ a. Heat transfer medium    | 1. Supplementary heat source other than solar.                                               |
| ___ b. Auxiliary energy system | 2. A liquid or gas which absorbs heat readily--is used to move heat away from the collector. |

2. A. Name and describe briefly the components of a warm-water flat-plate system,

1. \_\_\_\_\_

\_\_\_\_\_

2. \_\_\_\_\_

\_\_\_\_\_

3. \_\_\_\_\_

\_\_\_\_\_

B. From the following list, identify some advantages (A) and disadvantages (D) of a warm-water, flat-plate system. Not all statements will be applicable (NA).

- \_\_\_ 1. Leakage could be a problem.
- \_\_\_ 2. Corrosion could be a problem.
- \_\_\_ 3. Can use only direct radiation.
- \_\_\_ 4. Circulation of water uses less energy than the circulation of air with the same amount of heat content.
- \_\_\_ 5. Freezing is a potential problem.
- \_\_\_ 6. Initial cost is high.
- \_\_\_ 7. Less heat exchanger area is required than with an air system.
- \_\_\_ 8. Piping takes up less space than does duct work.
- \_\_\_ 9. The reflector surface must be kept clean.
- \_\_\_ 10. Water is a cheap and efficient heat transfer and storage medium.

3.A. Name and describe briefly the components of a warm-air flat-plate system.

1. \_\_\_\_\_

\_\_\_\_\_

2. \_\_\_\_\_

\_\_\_\_\_

3. \_\_\_\_\_

\_\_\_\_\_

B. From the following list, identify some advantages (A) and disadvantages (D) of a warm-air flat-plate system. Not all statements will be applicable (NA).

\_\_\_ 1. Leakage is not a problem.

\_\_\_ 2. Corrosion is not a problem.

\_\_\_ 3. Only direct radiation can be used.

\_\_\_ 4. The collectors and storage may need frequent cleaning.

\_\_\_ 5. Cost of equipment tends to be lower than with a water system of the same capacity.

\_\_\_ 6. More energy is required to transfer heat if air is used as the heat transport medium.

\_\_\_ 7. Ductwork requires a greater amount of space than does piping for fluids.

\_\_\_ 8. The reflector surface must be kept clean.

\_\_\_ 9. A larger heat exchange surface is needed for air than is needed for liquids.

\_\_\_ 10. The system does not require complicated controls.

4.A. Name and describe briefly the components of a warm-water concentrating system.

1. \_\_\_\_\_

\_\_\_\_\_

2. \_\_\_\_\_

3. \_\_\_\_\_

B. From the following list, identify some advantages (A) and disadvantages (D) of a warm-water concentrating collector. Not all statements will be applicable (NA).

- \_\_\_\_ 1. Leakage may present problems.
- \_\_\_\_ 2. The reflector surface must be kept clean.
- \_\_\_\_ 3. Water is a cheap and efficient heat transfer and storage medium.
- \_\_\_\_ 4. Only direct radiation can be collected.
- \_\_\_\_ 5. Higher temperatures can be obtained than can be obtained with flat-plate collectors.
- \_\_\_\_ 6. The absorber area needed is smaller than that needed with flat-plate collectors.
- \_\_\_\_ 7. Ductwork must be large.
- \_\_\_\_ 8. Costs could be lower because the collector forms lend themselves to mass production techniques.
- \_\_\_\_ 9. At present, concentrating collectors are more expensive.
- \_\_\_\_ 10. In climates with many sunless days, the system may not be applicable.

5.A. Name and describe the components of a warm-air passive system.

1. \_\_\_\_\_

2. \_\_\_\_\_

3. \_\_\_\_\_



B. From the following list, identify some advantages (A) and disadvantages (D) of a warm-air passive system. Not all statements will be applicable (NA).

- \_\_\_ 1. Automatic or manual insulating devices are expensive.
- \_\_\_ 2. Life style may need to be modified.
- \_\_\_ 3. Cost should be reduced through simpler technology.
- \_\_\_ 4. Elimination of separate collector should reduce cost.
- \_\_\_ 5. A vertical passive collector will require a larger unobstructed area for access to the sun.
- \_\_\_ 6. Ductwork is expensive and takes up a large amount of space.
- \_\_\_ 7. Leakage may be a problem.
- \_\_\_ 8. May not be cost-effective relative to air- or liquid-cooled collectors.
- \_\_\_ 9. Collector serves multiple functions.
- \_\_\_ 10. Large expanses of south-facing glass may cause problems about occupant-privacy.

ANSWERS TO UNIT TEST: REPRESENTATIVE SOLAR ENERGY SYSTEMS

Answers to Unit Test 1

- A. 3
- B. 8
- C. 7
- D. 5
- E. 1
- F. 2
- G. 4
- H. 6

Answers to Unit Test 2

- A. 1. Liquid-cooled flat-plate collectors have a flat absorbing surface to absorb both direct and diffuse radiation. The heat transfer fluid is piped across the absorbing surface.
- 2. Hot water is stored in an insulated concrete or steel tank. Heat from the collector is transferred to storage by means of a heat exchange coil.
- 3. Distribution is accomplished by pumping the hot water from storage through pipes to baseboard heaters.
- B. 1. D
- 2. D
- 3. NA
- 4. A
- 5. D
- 6. D
- 7. A
- 8. A
- 9. NA
- 10. A

### Answers to Unit Test 3

- A. 1. The air-cooled flat-plate collector has a solid absorbing surface to collect direct and diffuse radiation. Air is pumped through the collector.
2. The hot air is blown into the rock storage. The rocks are about 2 inches in diameter and the container is insulated.
3. The hot air is pumped through ducts to the rooms.
- B. 1. A
2. A
3. NA
4. D
5. A
6. D
7. D
8. NA
9. D
10. NA

### Answers to Unit Test 4

- A. 1. The linear collector captures only direct radiation, which the reflecting surface concentrates on a glass-enclosed pipe. The pipe, usually painted black, is the absorber. The heat transfer medium circulates through the pipe.
2. The storage unit is a well-insulated, leak proof tank for storing hot water.
3. Distribution is accomplished by pumping the heated water to baseboard heaters located throughout the building.

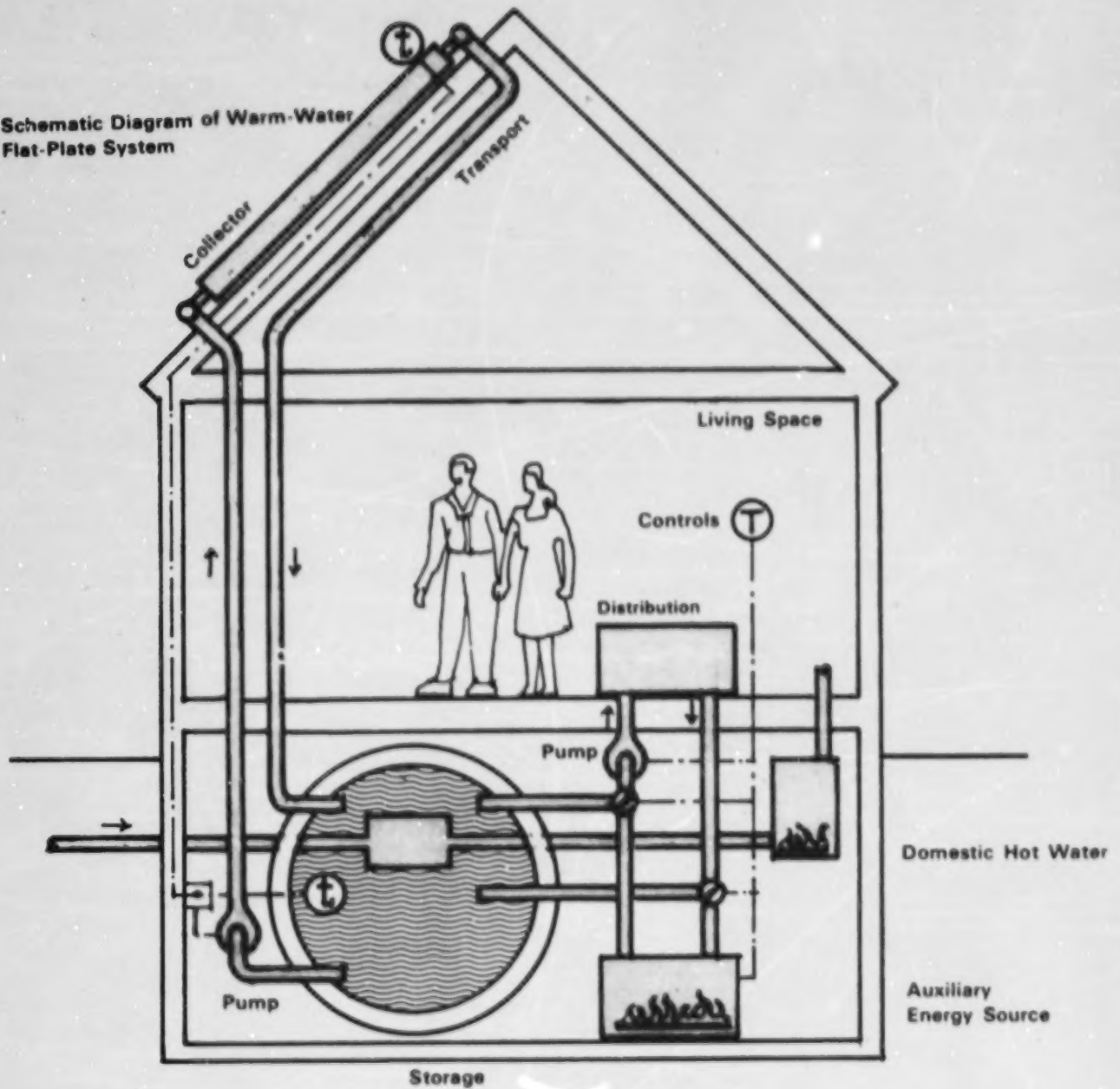
- B. 1. D  
2. D  
3. A  
4. D  
5. A  
6. A  
7. NA  
8. A  
9. D  
10. D

Answers to Unit Test 5

- A. 1. The collector is a massive south-facing wall of masonry or concrete separated by an air space from an outer wall of glass. It will capture reflected, direct, and diffuse radiation (a Trombe Wall).  
2. Storage is the exposed wall, a rock pile under the floor, and other internal surfaces which absorb heat radiated from the south wall.  
3. Distribution is by convection, radiation, and conduction. Also heated air is transported through ducts to storage and from storage to the living space. A small fan may be needed to assist natural means of heat transfer.

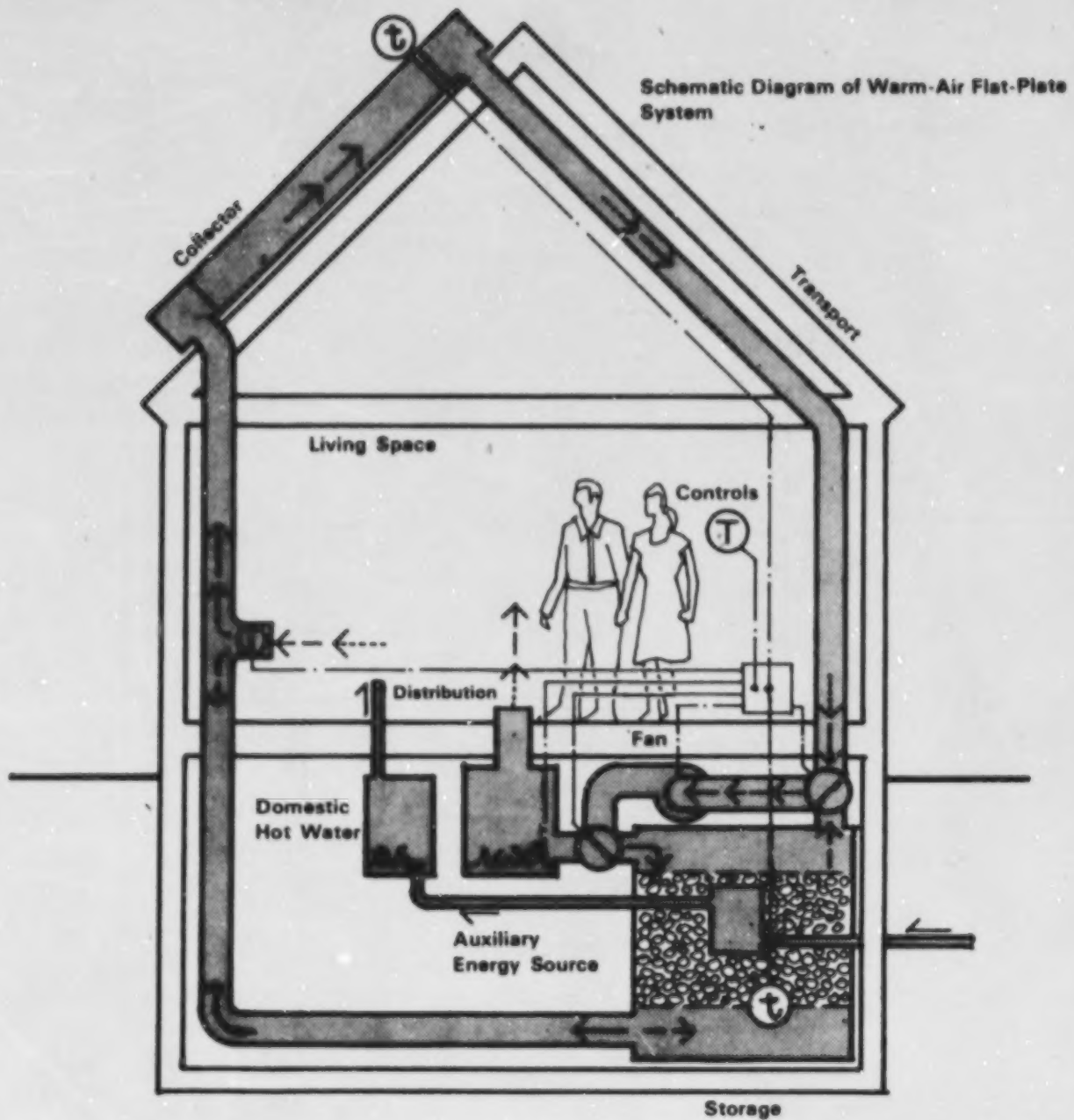
- B. 1. D  
2. D  
3. A  
4. A  
5. D  
6. NA  
7. NA  
8. D  
9. A  
10. D

Schematic Diagram of Warm-Water Flat-Plate System



From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.

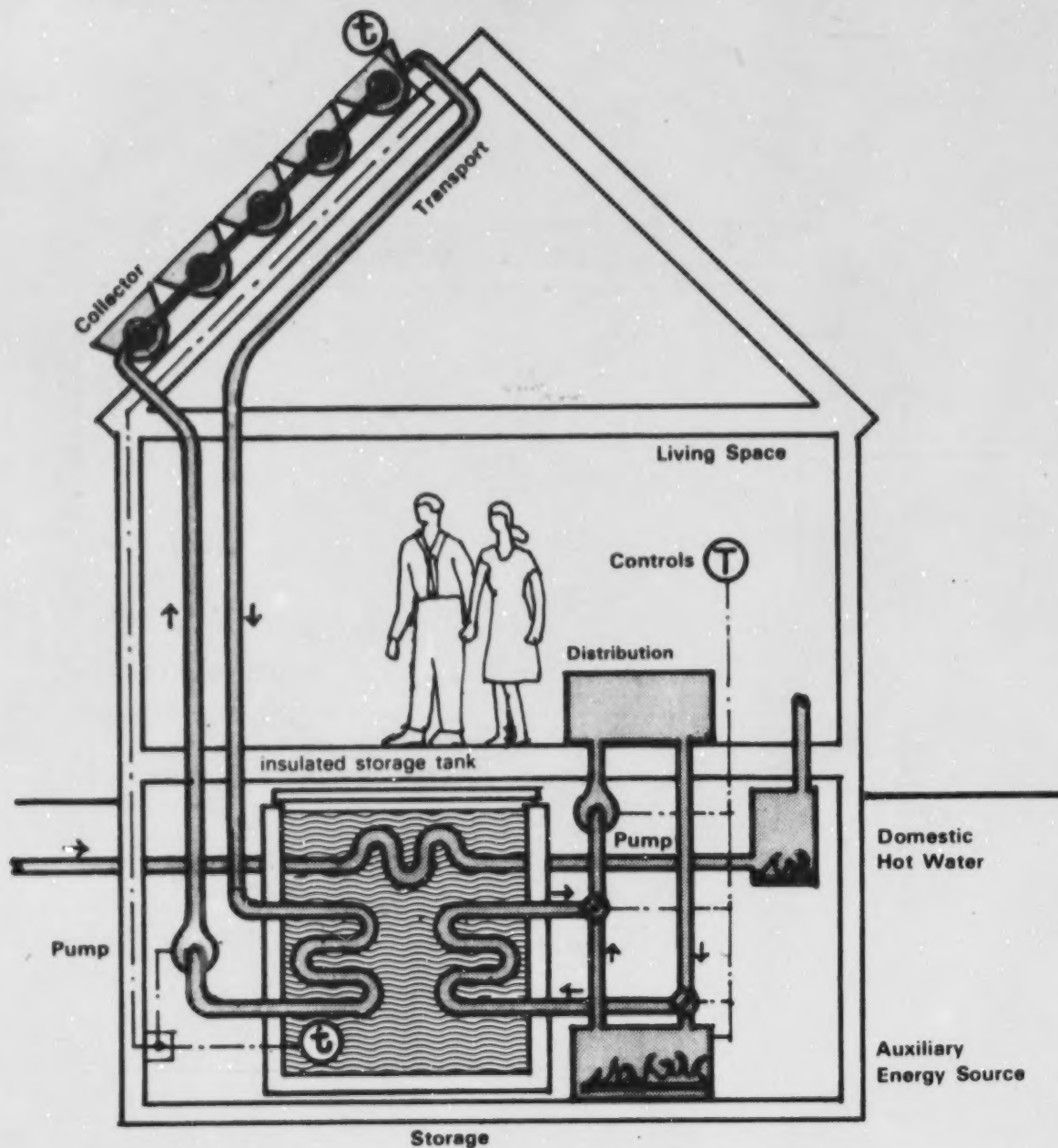




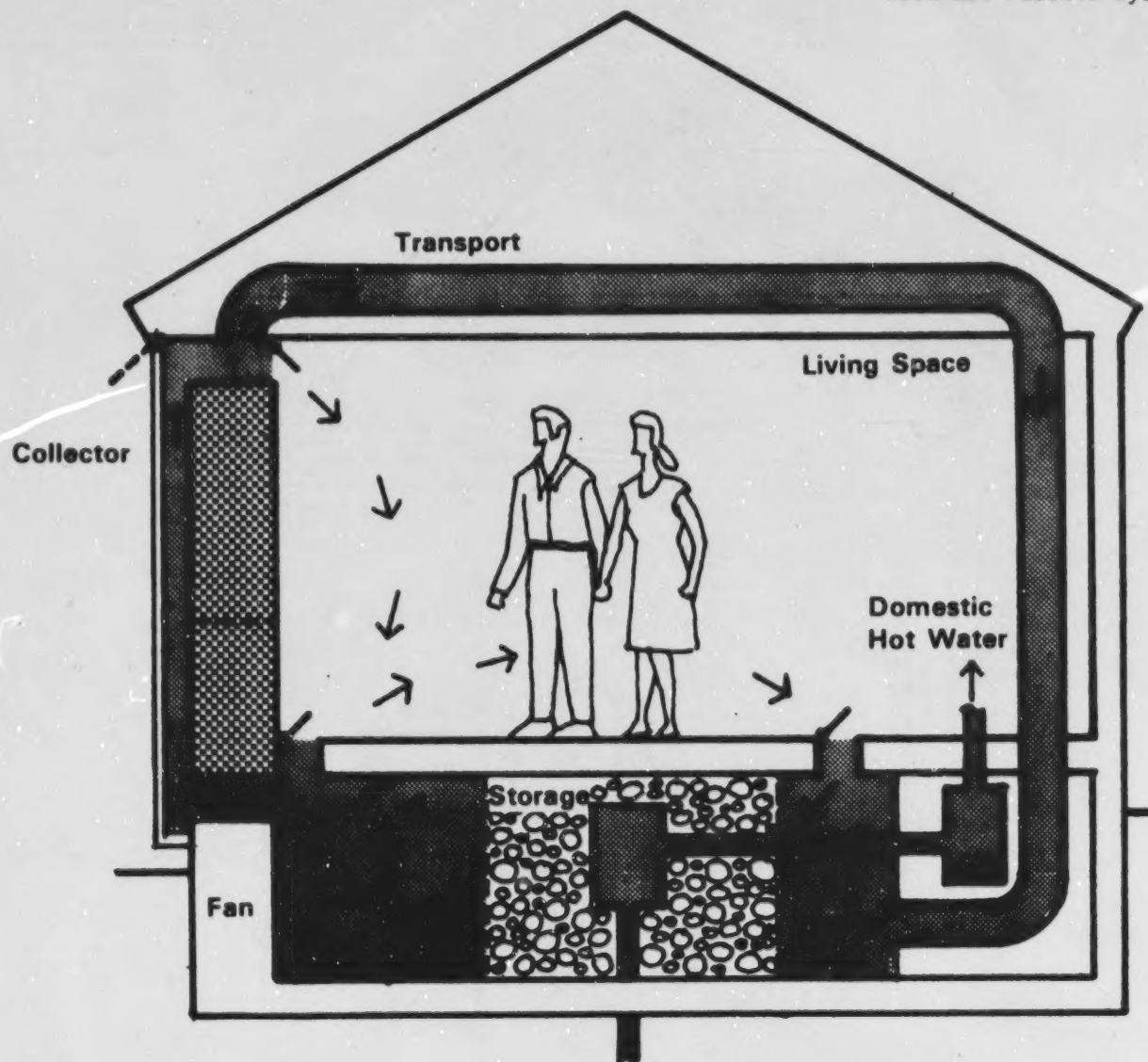
From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.

Transparency 7.3

Schematic Diagram of Warm-Water Concentrating System



From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C., Government Printing Office, May 1976.



From AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C.,  
Government Printing Office, May 1976.

## GLOSSARY

**Active Solar Energy System** - thermal energy is transported from the collectors to storage and then to the distribution system in a regulated way, using mechanical pumps and thermal controls.

**Air-Cooled Collector** - a type of flat-plate collector in which air is used as the heat transport medium.

**Angle of Declination** - see Declination angle.

**Angle of Incidence** - see Incidence angle.

**Beadwall** - a patented insulated window in which polystyrene beads are blown into or pulled out of a space between two sheets of glass or plastic by a vacuum-driven system.

**Biomass conversion** - energy from the sun is stored through the process of photosynthesis in plants, i.e., in organic material. Chemical processes can be used to change the organic material to simpler forms with an accompanying release of energy.

**Btu** - British thermal unit, a measure of heat.

**Change-of-state** - the physical form of matter changes from solid to liquid to gas. For example, water can be changed to a solid (ice) or a gas (steam). When changes of state occur, energy is either used or released in the process.

**Circular Concentrating Collector** - a type of concentrating collector which is circular in shape so that the affected solar radiation is focused on an absorbing surface.

**Clerestory Window** - a south facing window in the wall of a room which rises above an adjoining roof; the window can be used to admit solar radiation.

**Collector** - the component in a solar energy system which receives solar radiation and converts it to heat.

**Collector-tilt** - the angle measured from the horizontal at which a solar collector is tilted to face the sun for better performance.



**Concentrating Collector** - a class of collectors which use reflectors to focus solar radiation on a small area.

**Conduction** - Heat flows through different materials at varying rates. Copper is an excellent conductor of heat; insulating materials are poor conductors. Heat transfer by conduction occurs only when two surfaces are in direct physical contact because heat transfer is caused by molecular scale vibration.

**Convection** - when two surfaces, one hot, the other cold, are separated by a thin layer of air, moving air currents are established that carry heat from the hot to the cold surface. In convection, heat transfer is by large-scale fluid motion.

**Convection** - when two surfaces, one hot, the other cold, are separated by a thin layer of air, moving air currents are established that carry heat from the hot to the cold surface. In convection, heat transfer is by large-scale fluid motion.

**Declination angle** - the angle between the plane of the earth's rotation around the sun and the earth's equatorial plane in a direction facing the sun.

**Diffuse radiation** - the solar radiation striking the surface of the earth after its direction has been changed by reflection and scattered by particles in the atmosphere--nondirectional rays.

**Direct radiation** - direct or parallel rays from the sun.

**Distribution** - the component in a solar energy system whereby the thermal energy in storage is made available at the point of use.

**Earth-Sunline** - an imaginary line between the center of the sun and the center of the earth.

**Energy** - the ability to do work.

**Equatorial plane** - an imaginary plane through the earth's equator and perpendicular to the north-south axis.



**Penetration** - the placement, size, and design of windows and doors in a building.

**Flat-Plate Collector** - a class of collectors so named because of the large surface area exposed to the sun.

**Heat-transport fluid** - a liquid or gas which absorbs heat efficiently and moves the heat away from the collector to storage or to point of use. Also called heat transfer medium.

**Incidence Angle** - the angle between the line for direct rays and a line perpendicular to the irradiated surface.

**Insolation** - the amount of solar radiation actually striking the surface of the earth.

**Irradiation** - exposure to radiant energy.

**Latitude** - the angular distance north or south from the earth's equator measured through  $90^{\circ}$ .

**Linear Concentrating Collector** - a type of concentrating collector, oblong in shape, which focuses the reflected radiation onto a tube through which the transport medium is circulated.

**Liquid-Cooled Collector** - a type of flat-plate collector in which the liquid used as the heat transport medium, is piped through the collector box.

**Nonrenewable energy source** - a substance found in nature which cannot be replenished and which can be used to obtain energy in some form. Coal, gas, uranium are examples of nonrenewable energy sources.

**Open-water collector** - a type of flat-plate collector in which the heat transport medium, usually water, is trickled down grooves rather than piped through the collector.

**Passive Solar Energy System** - heat is transported by natural means, and the components are typically integrated into the basic design of the dwelling, so that few, if any, mechanical devices are needed in the system.

Photovoltaic - direct conversion of the sun's energy to electricity.

Radiation - any object which is warmer than its surroundings transmits heat waves (similar to light waves, but invisible) and, thus, emits energy.

Heat transfer occurs by photons.

Renewable energy source - a substance which occurs in nature and the supply of which cannot be depleted by use.

Solar Altitude - the angle of elevation of the sun above the horizon.

Solar Azimuth - the angle on a horizontal surface which measures the difference between the direction of a fixed point (e.g., true south) and the direction of the sun.

Solar Constant - the amount of solar energy striking the outer atmosphere of the earth varies only slightly and can be treated as a constant.

Solar Energy System - a grouping of parts designed to use energy from the sun. The parts, or components, are the collector, storage, and distribution. One or several components may themselves be sub-systems, i.e., systems within the system.

Solar Noon - that time of day when the azimuth angle is  $0^{\circ}$ , when the sun is due south of an observer.

Storage - the component in a solar energy system which retains the solar energy which has been collected for later use either at night or on cloudy days.

System - a regularly interacting (or interdependent) group of components forming a unified whole.

Thermal pollution - the discharge of heated waste into the natural environment at a temperature detrimental to existing ecosystems.

Thermosyphoning - the principle that heated gasses and liquids rise naturally has been applied as a means of heat transport in passive solar energy systems. Heat built up within a wall or roof structure can be drawn off to heat interior spaces.

Transmittance - the fraction of solar radiation which having entered a layer of absorbing material, flows to its further boundary.

Trombe Wall - a type of passive collector which makes use of a massive masonry wall, painted black and placed behind a south-facing wall of glass. Air trapped between the wall and the glass is heated, moves up over the wall and into the interior space.

Watts - a measure of power in the metric system ( e.g., a 25-watt light bulb).



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Transparency Masters  
for use with  
UNDERSTANDING SOLAR ENERGY SYSTEMS  
Instructional Modules

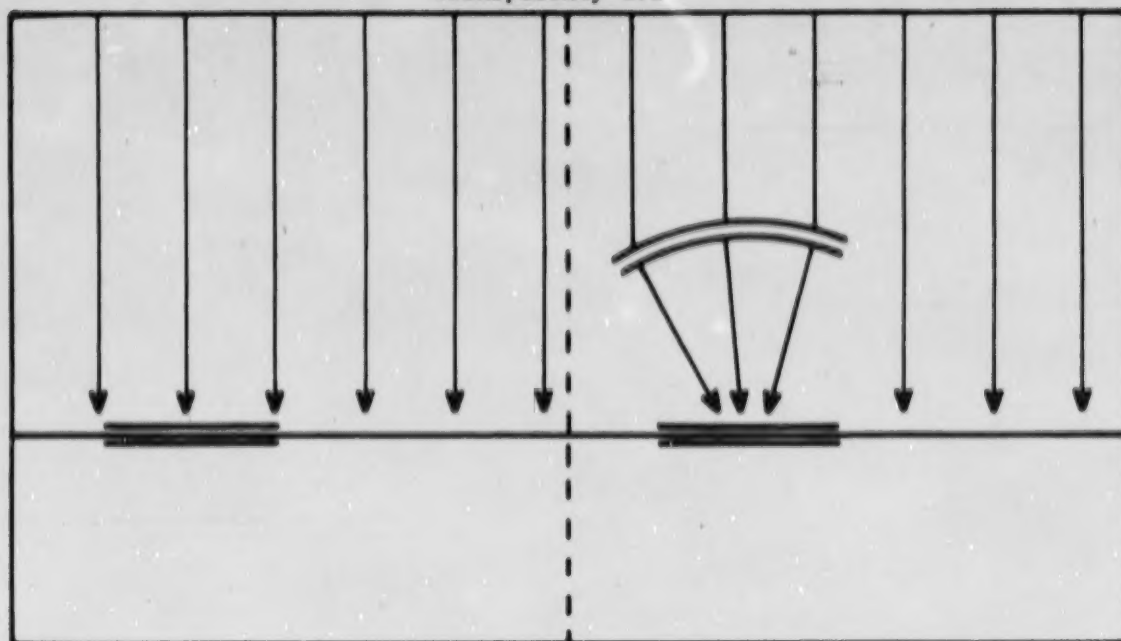
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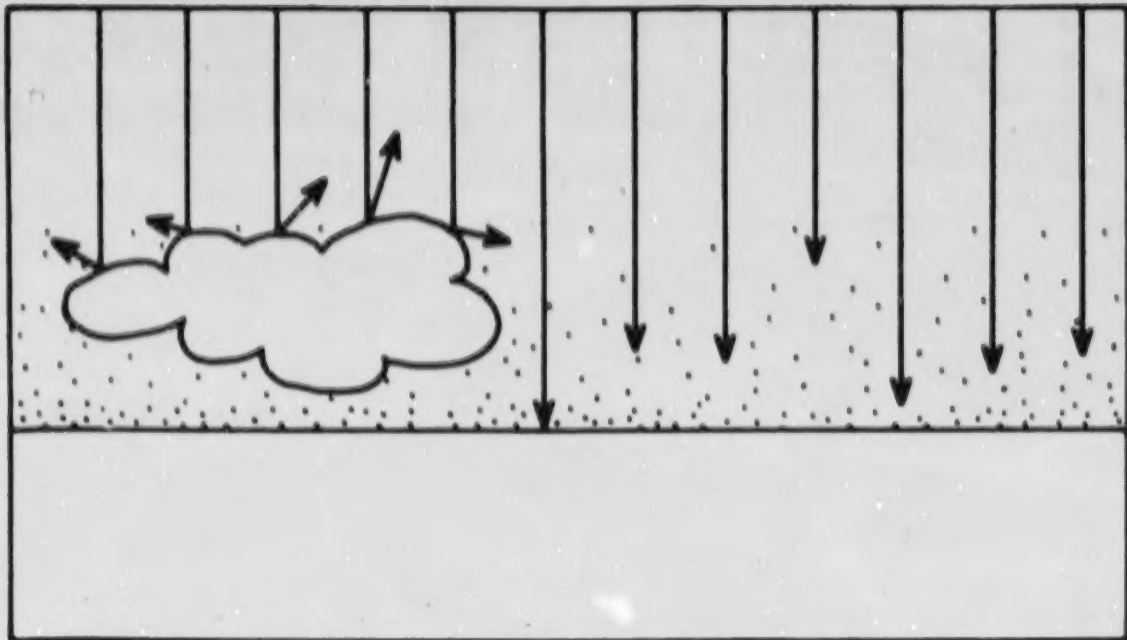


## 1. SOLAR CONSTANT

THERE IS A NEARLY CONSTANT AMOUNT OF SOLAR ENERGY STRIKING THE OUTER ATMOSPHERE — 429 BTU PER S.F. PER HOUR — AND THIS QUANTITY IS KNOWN AS THE SOLAR CONSTANT

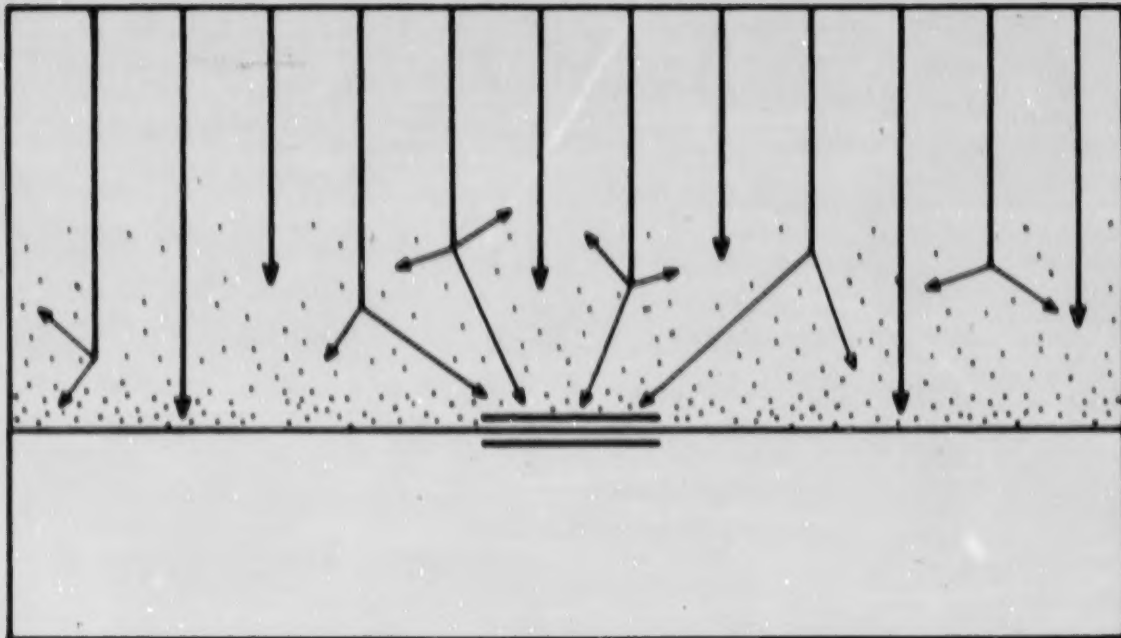
### NOTE

You cannot increase the amount of solar energy striking a collector of a given size by focusing. You may increase the collector's efficiency, or the temperature of the working fluid.



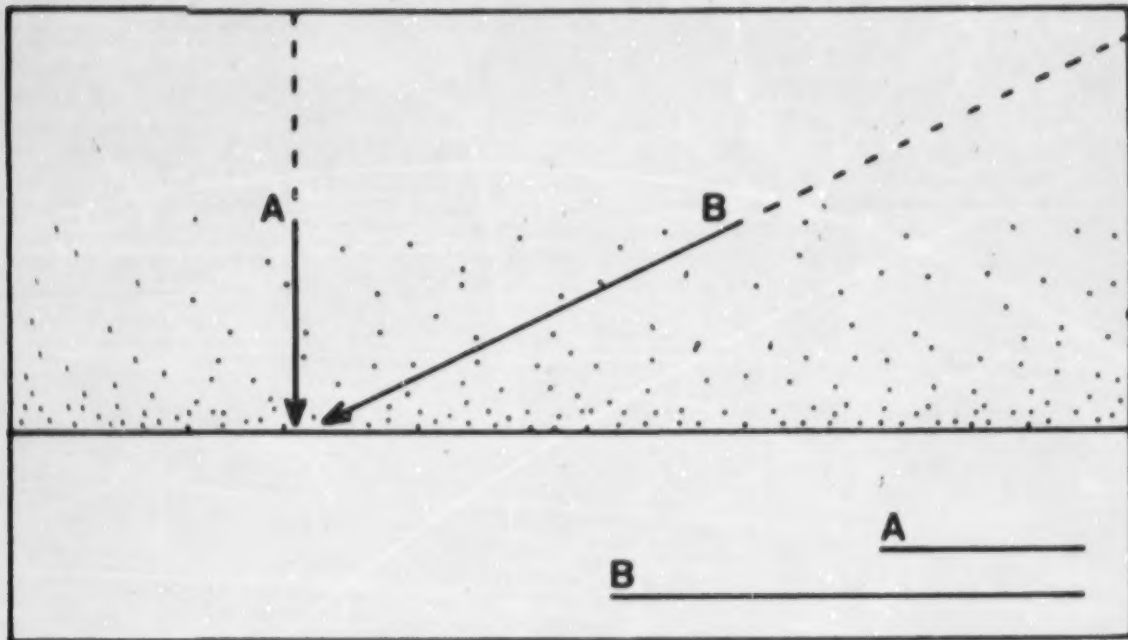
#### **4. ABSORPTION AND REFLECTION**

NEARLY HALF THE SOLAR RADIATION ENTERING THE EARTH'S ATMOSPHERE IS LOST THROUGH ABSORPTION BY MATERIAL IN THE ATMOSPHERE, OR BY REFLECTION FROM CLOUDS.



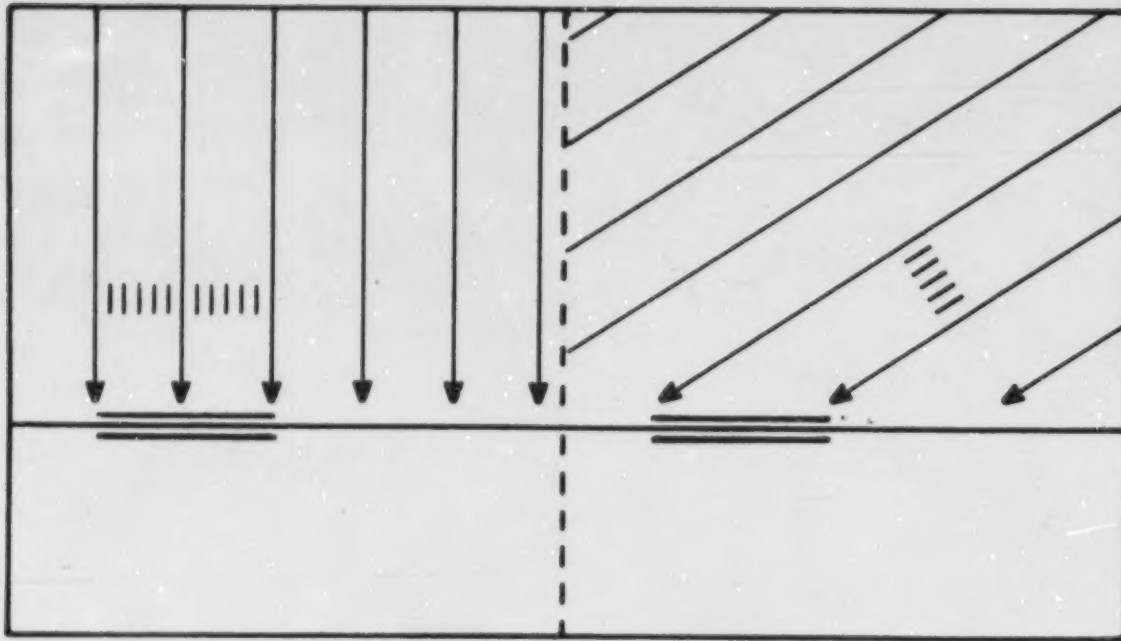
## 6. DIFFUSE RADIATION

CLOUDS AND PARTICLES IN THE ATMOSPHERE NOT ONLY REFLECT AND ABSORB SOLAR ENERGY, BUT SCATTER IT IN ALL DIRECTIONS BECAUSE OF THIS, SOLAR ENERGY IS RECEIVED FROM ALL PARTS OF THE SKY — MORE SO ON HAZY DAYS THAN ON CLEAR DAYS SUCH RADIATION IS CALLED *DIFFUSE*, AS OPPOSED TO THE NORMAL *DIRECT* RADIATION.



## 5. LENGTH OF TRAVEL THROUGH THE ATMOSPHERE

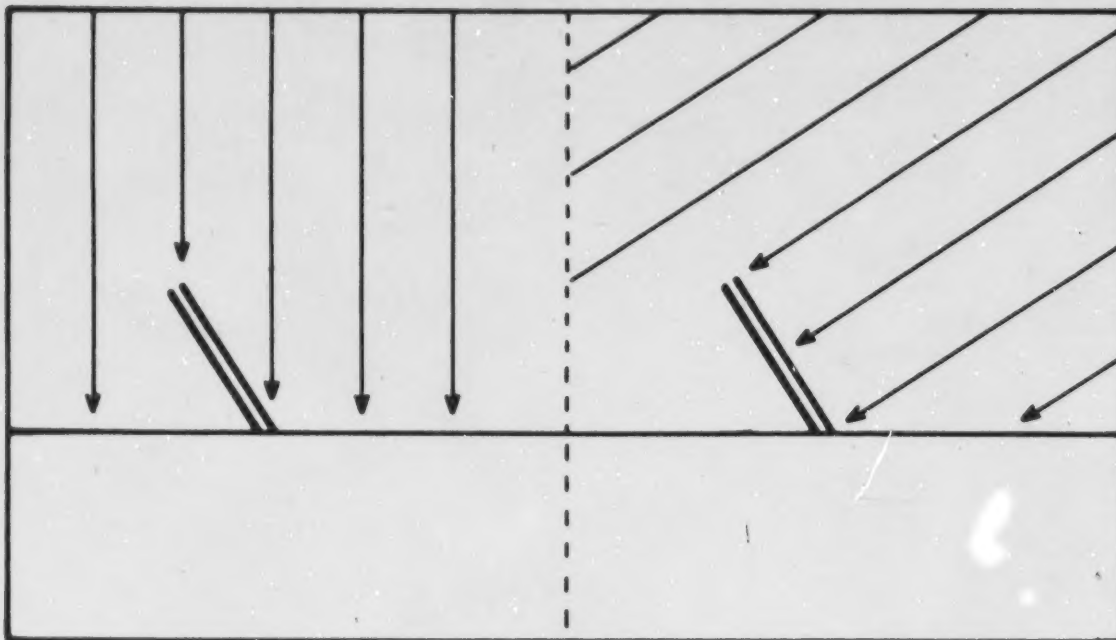
MORE SOLAR RADIATION IS LOST BY ABSORPTION AT LOW SUN ANGLES BECAUSE THE LENGTH OF TRAVEL THROUGH THE ATMOSPHERE IS GREATLY INCREASED (THAT IS WHY YOU CAN LOOK DIRECTLY AT THE SUN AT SUNSET.) HIGH ALTITUDES HAVE MORE SOLAR RADIATION FOR THE SAME REASON.



## 2. COSINE LAW — HORIZONTAL SURFACE

LESS SOLAR RADIATION STRIKES A GIVEN HORIZONTAL AREA AS THE SUN GETS LOWER IN THE SKY. THE AMOUNT CHANGES BY THE COSINE OF THE ANGLE, MEASURED FROM DIRECTLY OVERHEAD

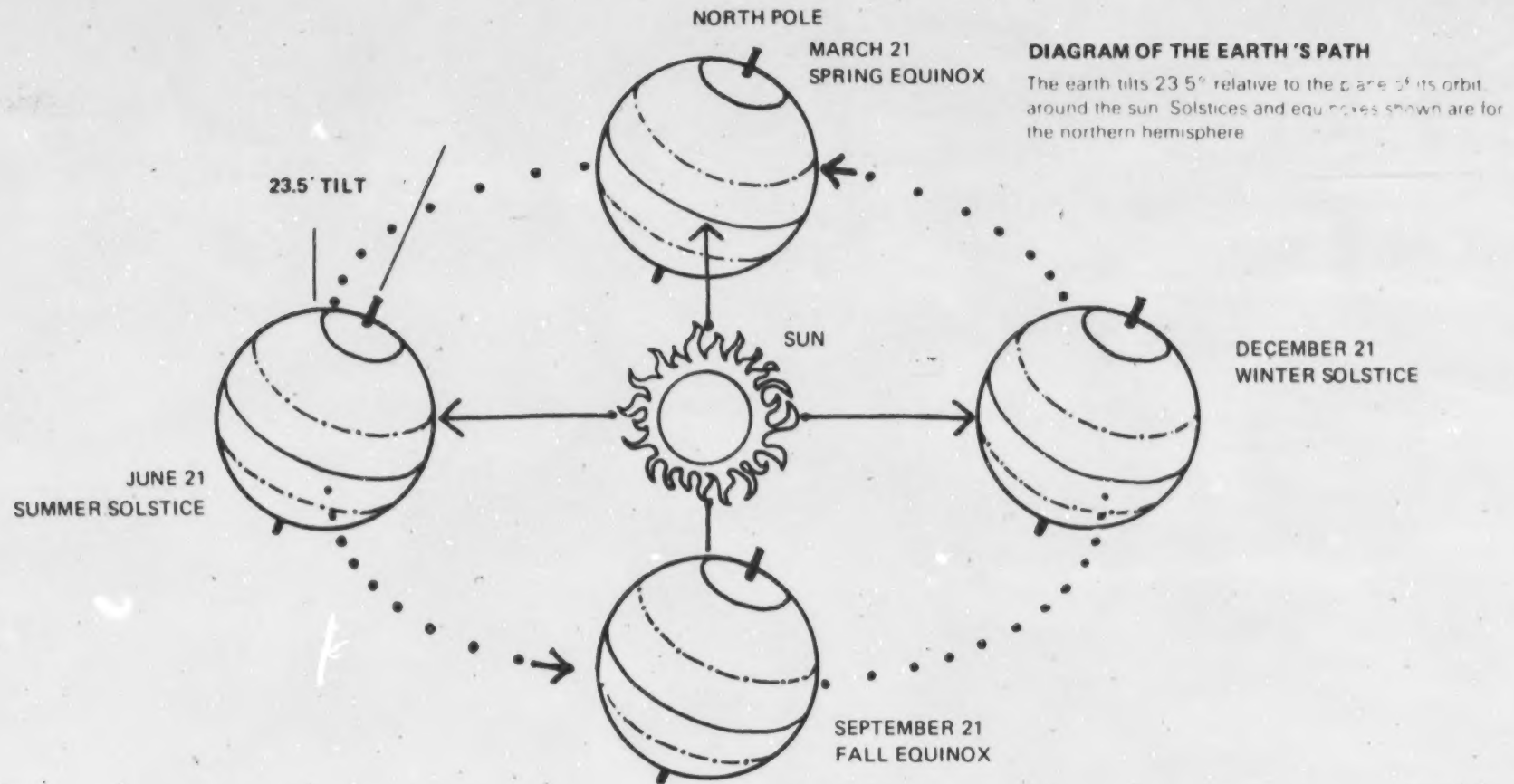




### 3. COSINE LAW — TILTED SURFACE

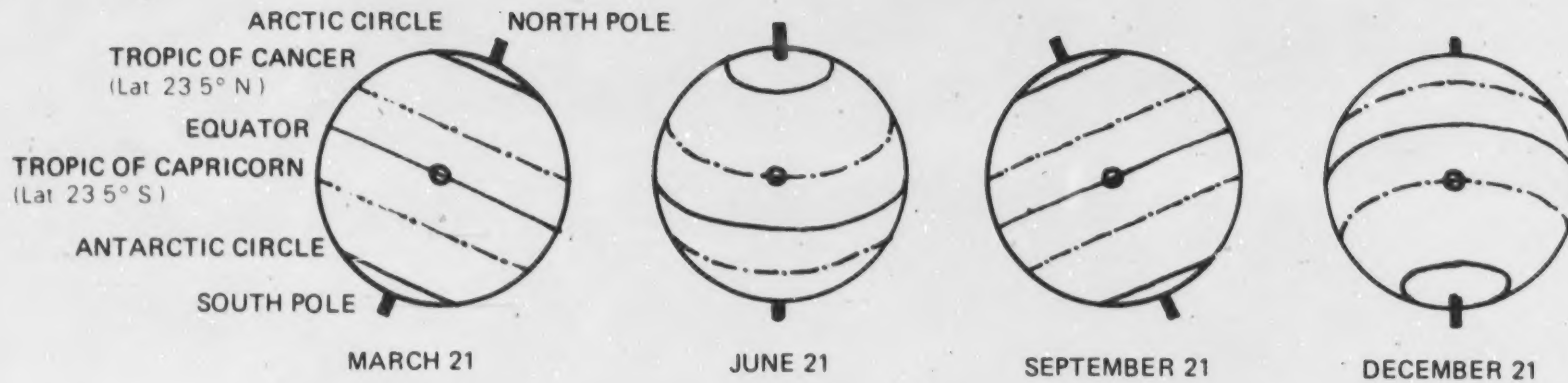
THE SAME LAW APPLIES TO A TILTED SURFACE, SUCH AS A SOLAR COLLECTOR. BY TILTING THE COLLECTOR SO THAT IT IS MORE NEARLY PERPENDICULAR TO THE SUN, MORE ENERGY STRIKES ITS SURFACE.

Transparency 2.1

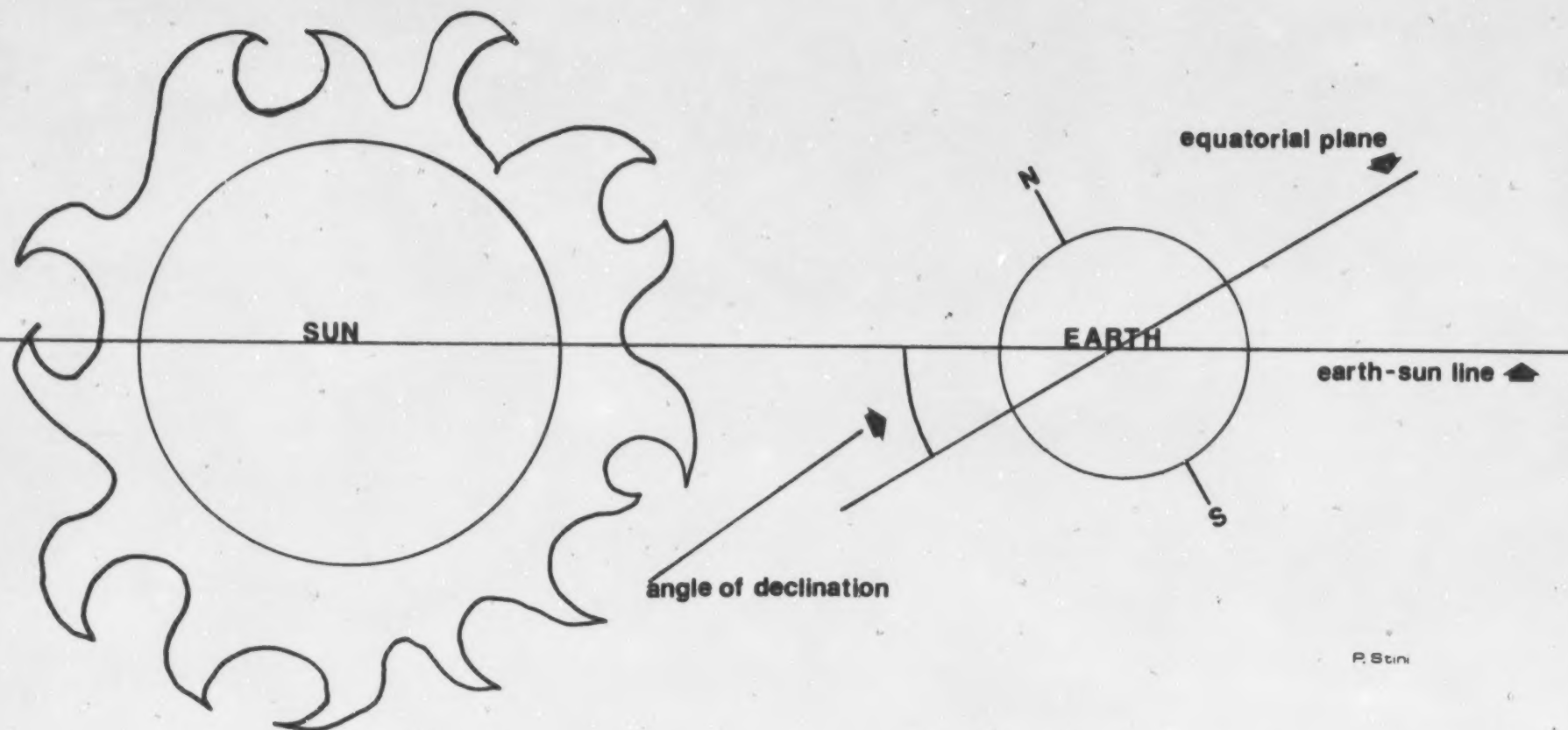


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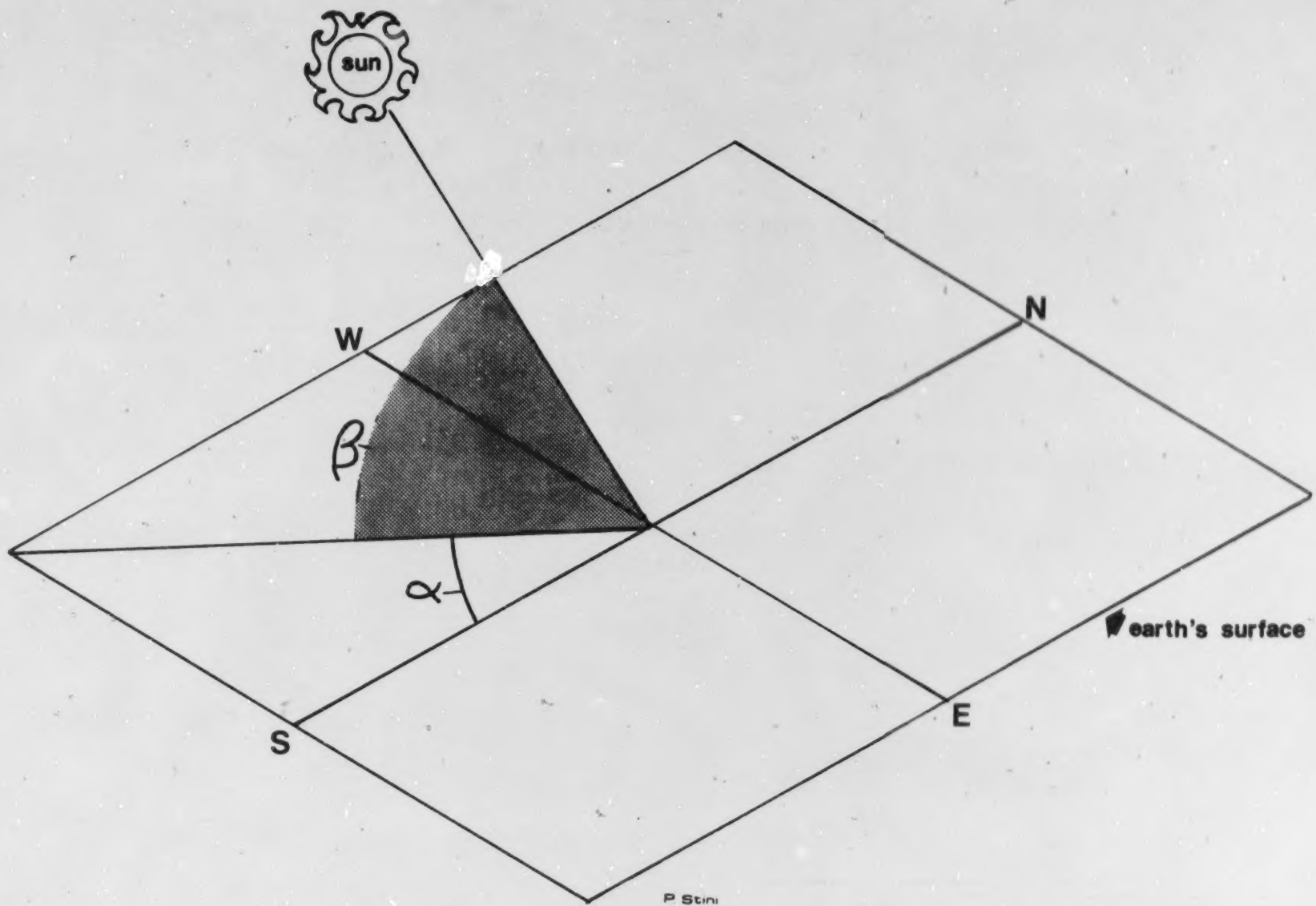
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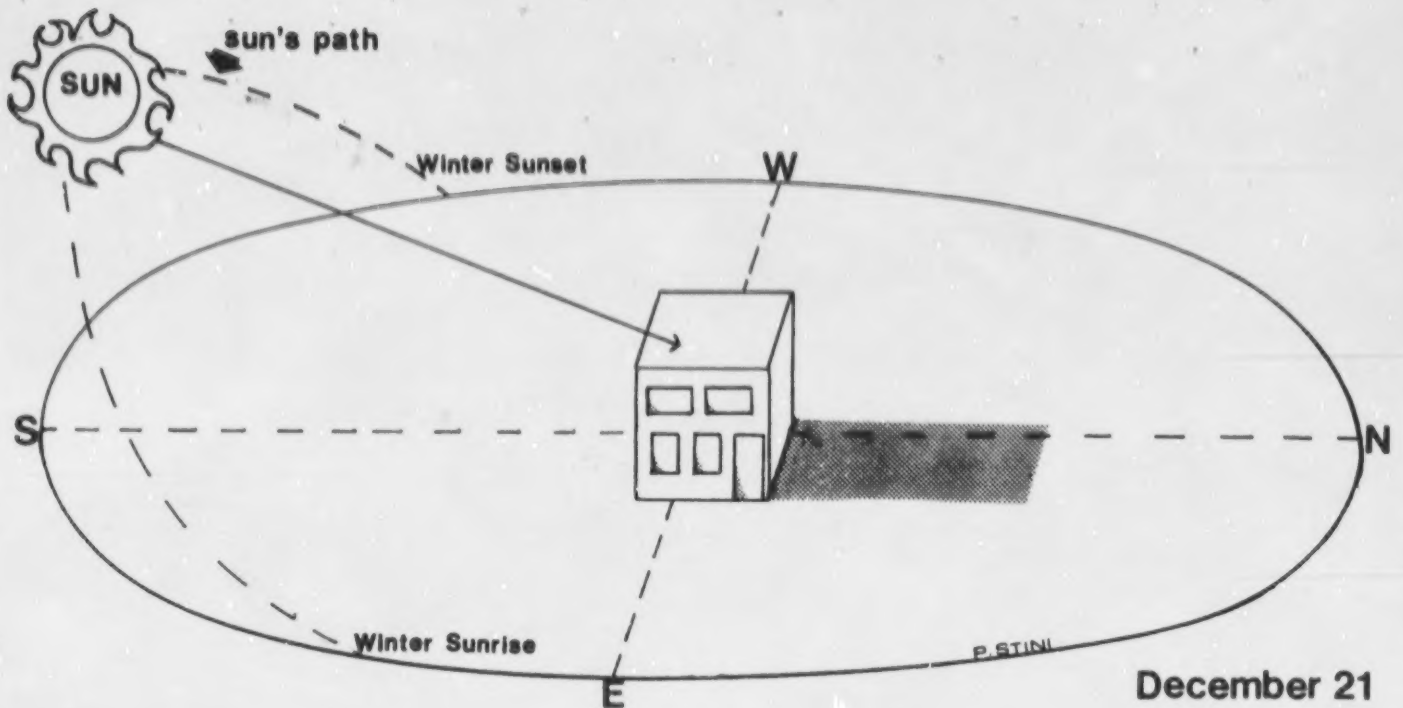
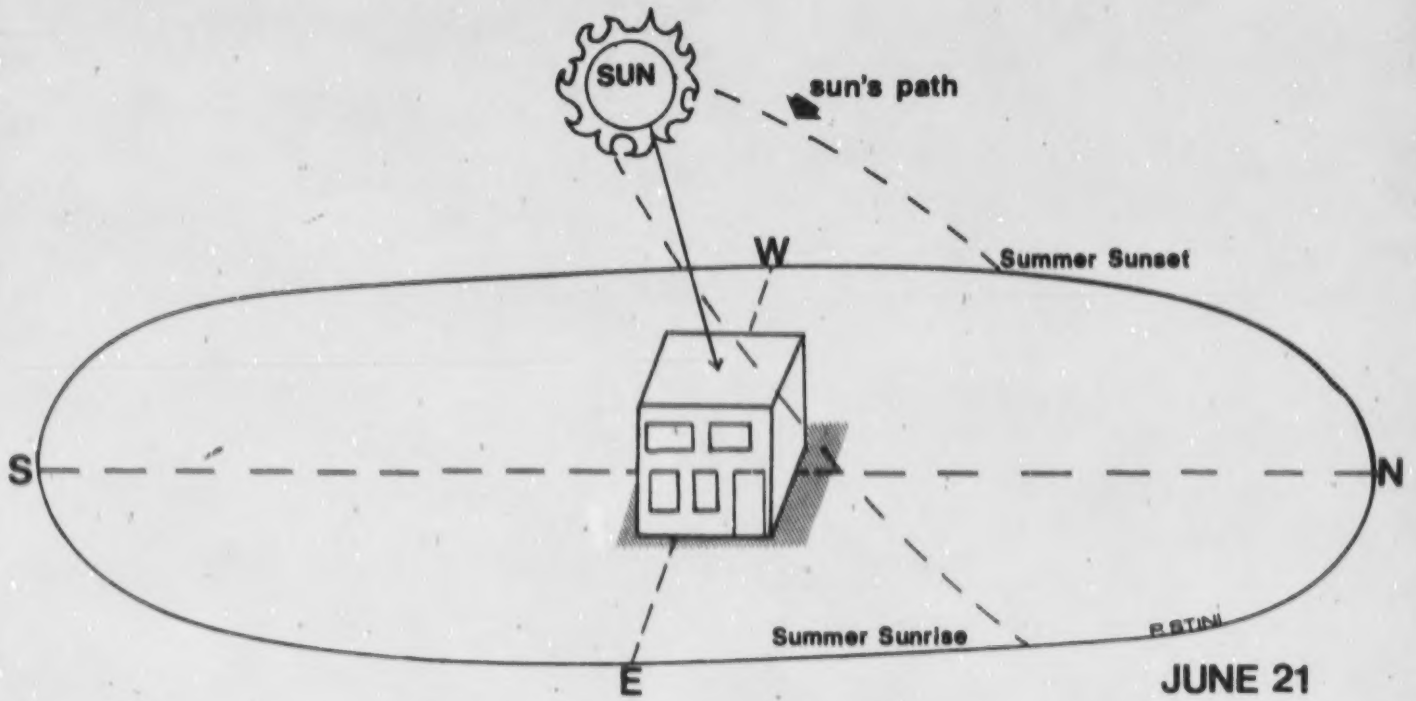


P. Stink

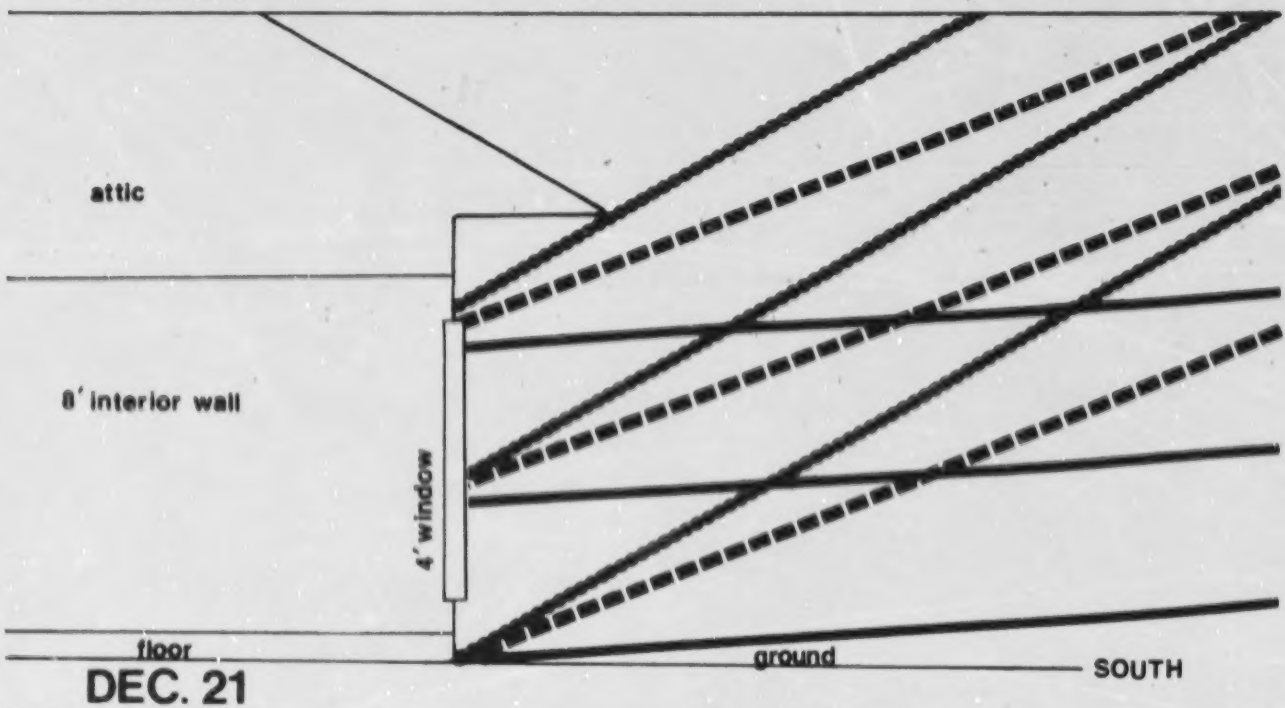
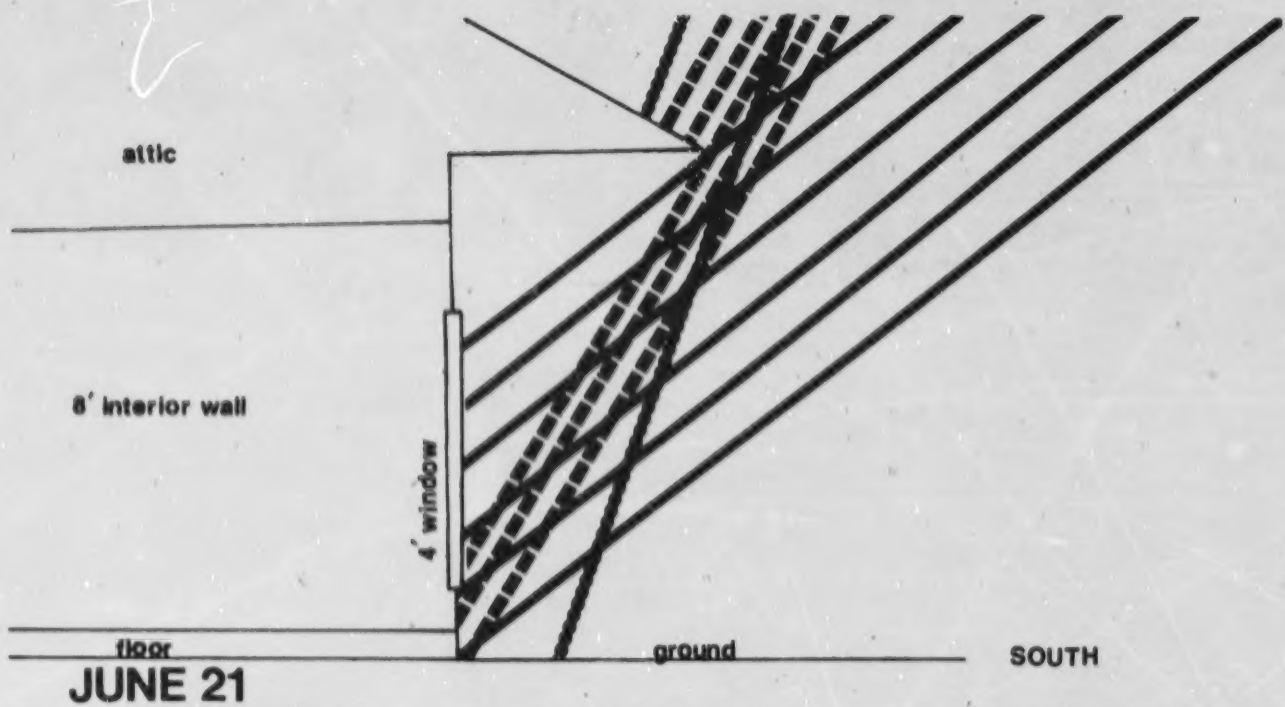




Transparency 2.5



# Transparency 2.6



Direct solar rays on south window of house

———— SOLAR NOON

----- 10 00 A.M.

———— 8 00 A.M.

Latitude 240° NORTH

P. Stini

COLLECTOR TILT

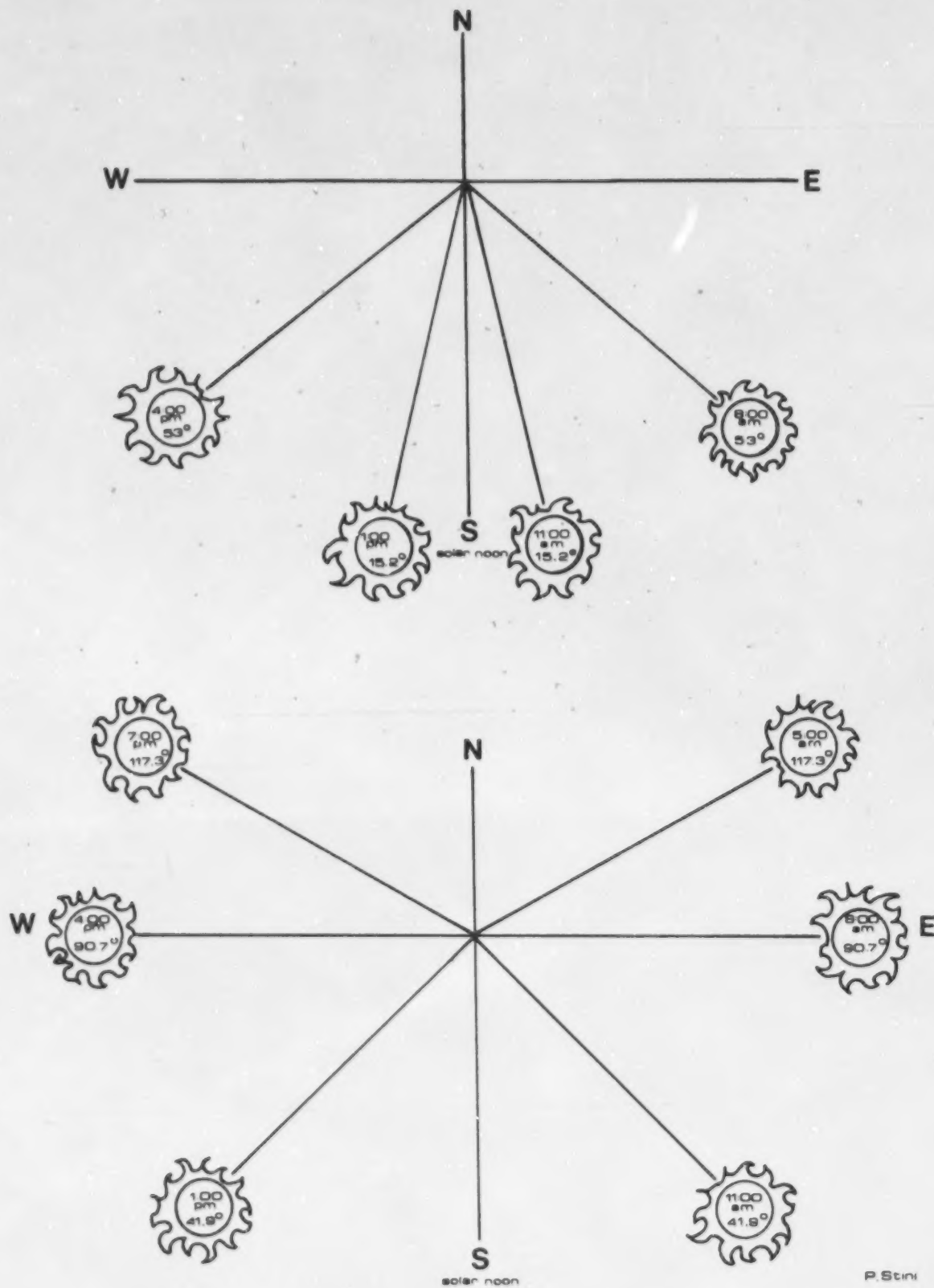
FLAT-PLATE COLLECTOR

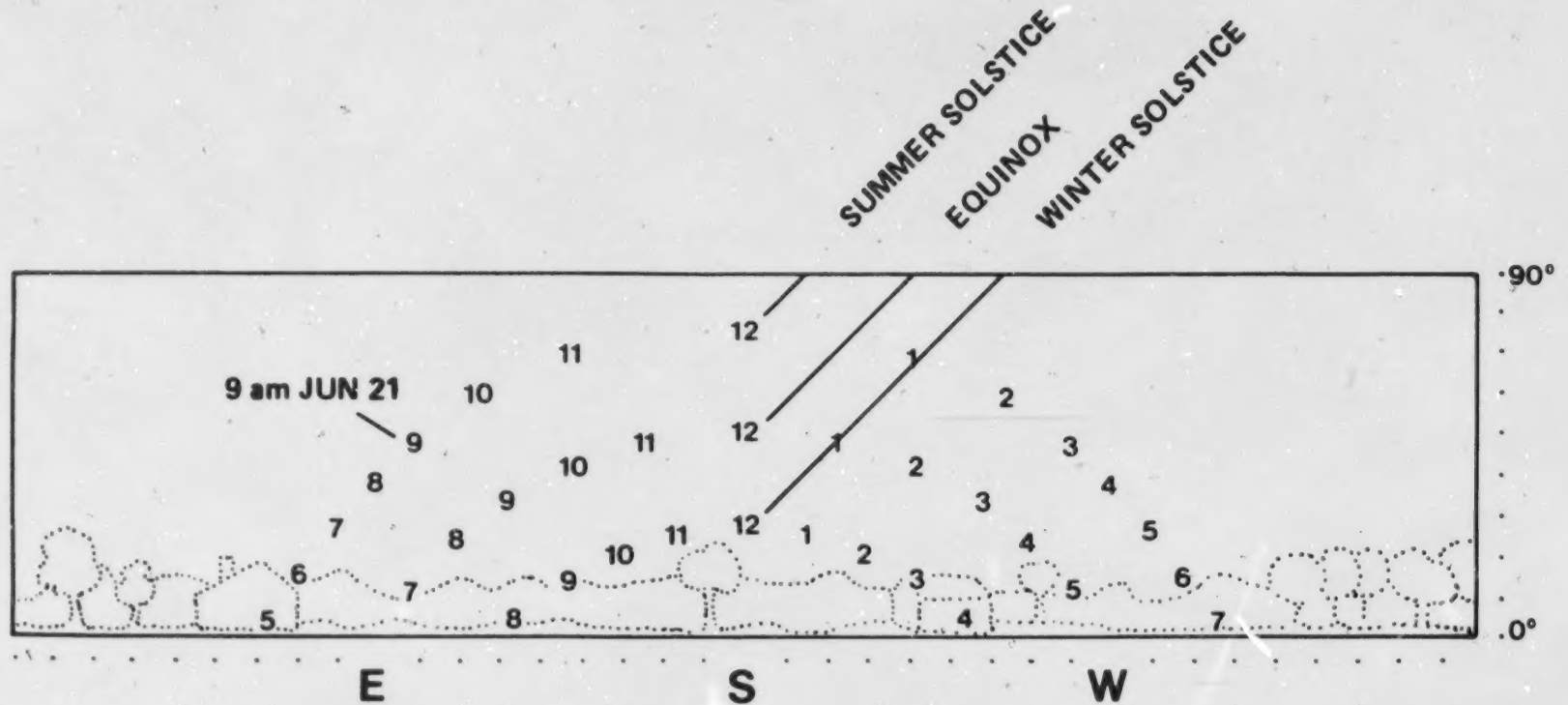
DIRECT RAYS OF SUN

HOUSE

EARTH'S SURFACE

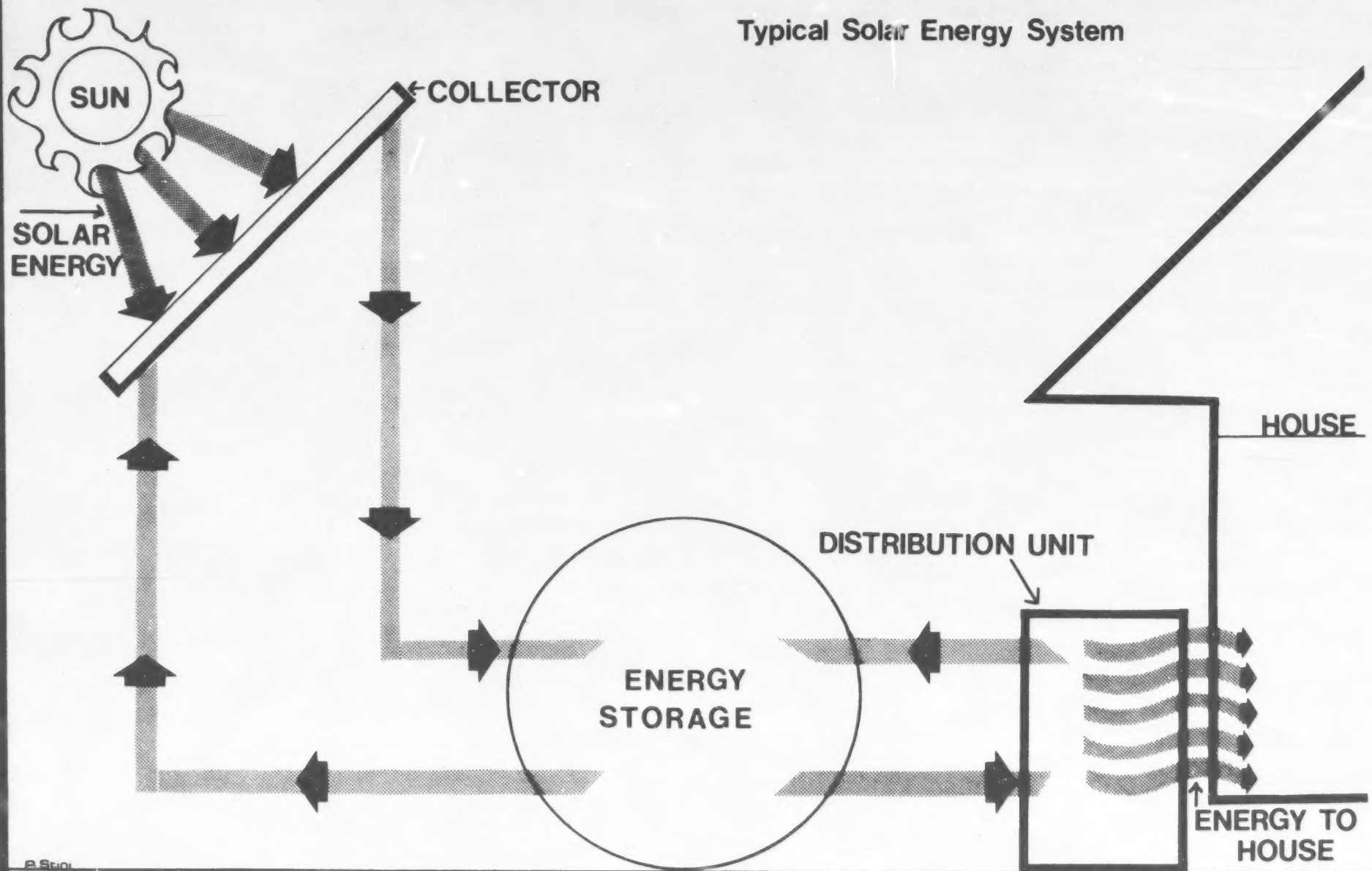
# Transparency 2.8



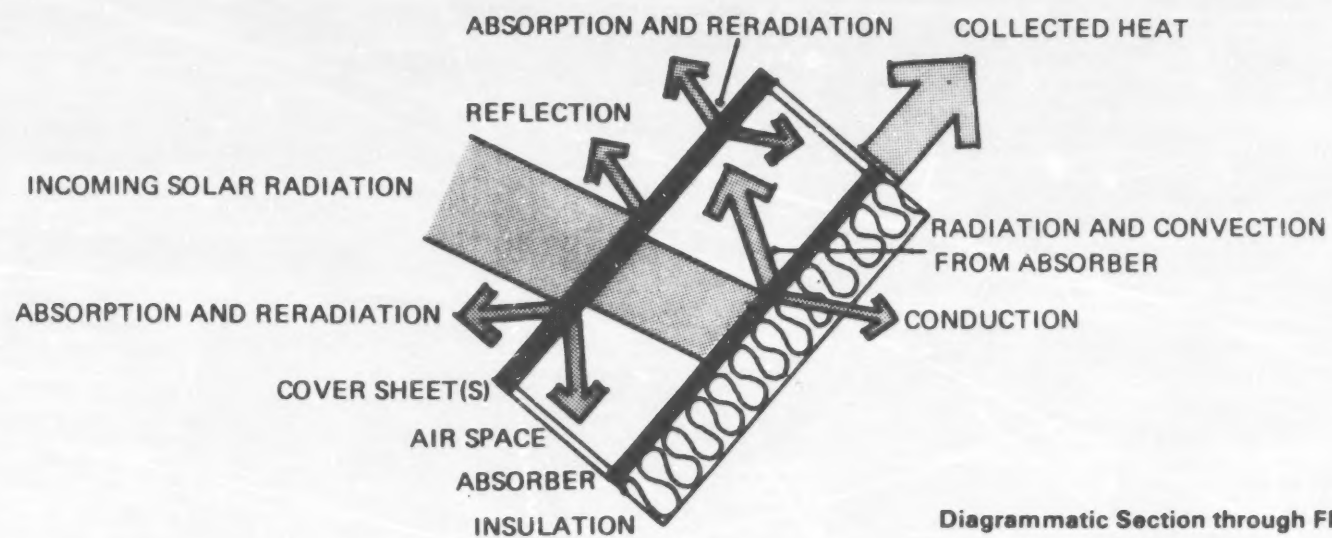




# Typical Solar Energy System



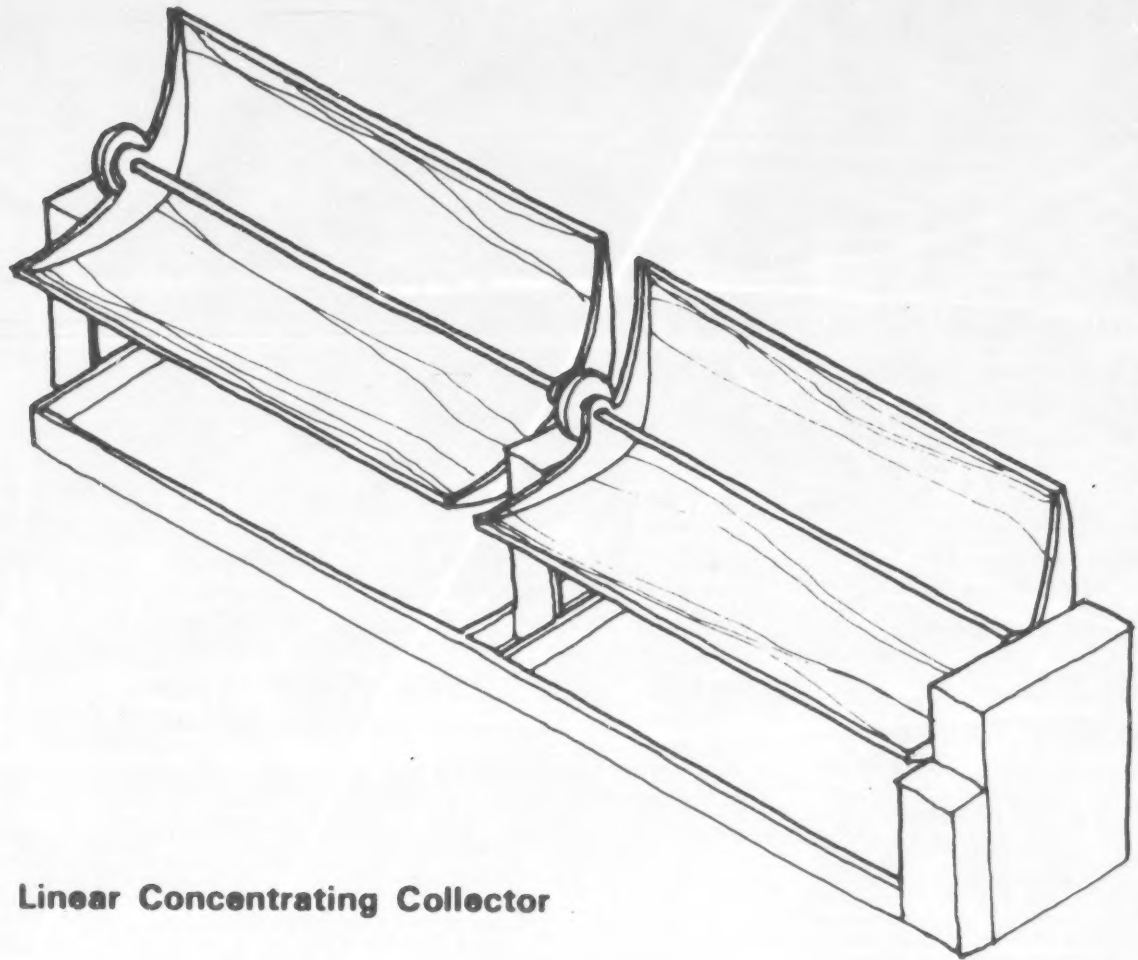
Transparency 4.1



Diagrammatic Section through Flat-Plate Collector

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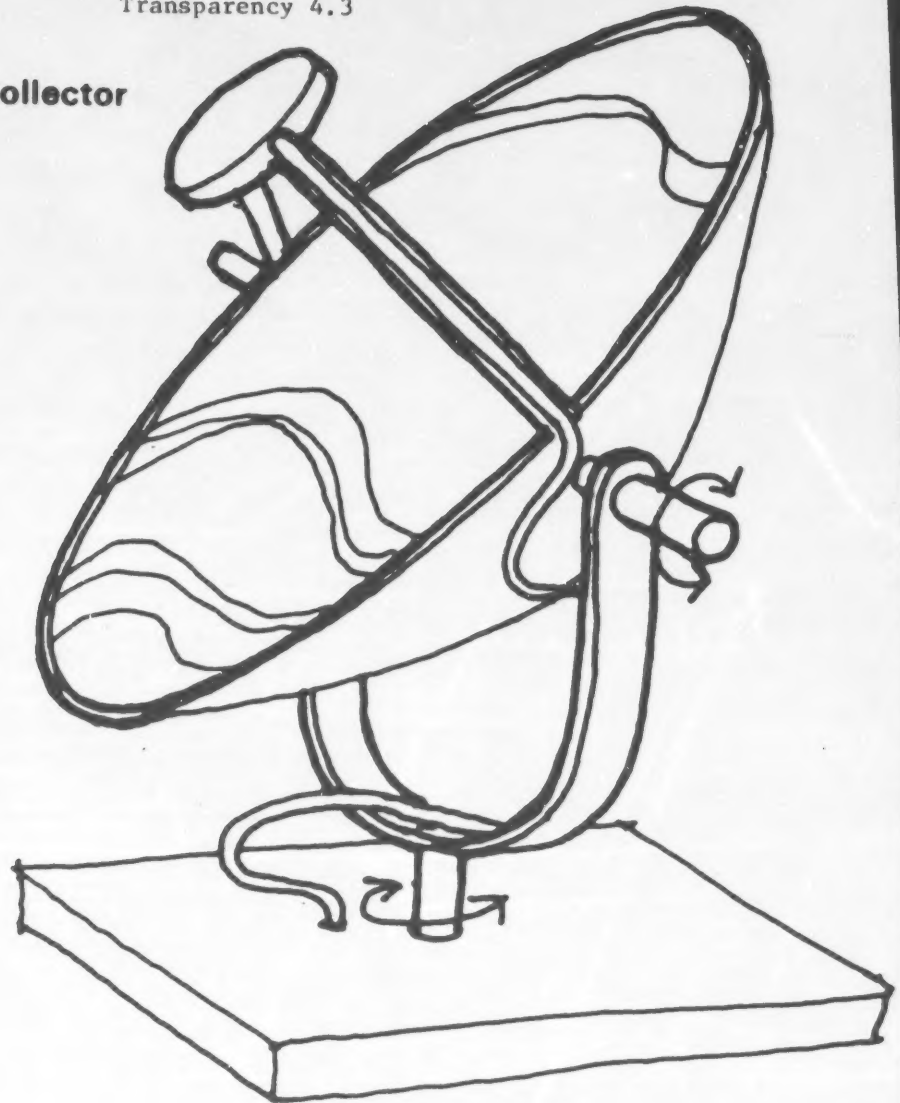
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**Linear Concentrating Collector**

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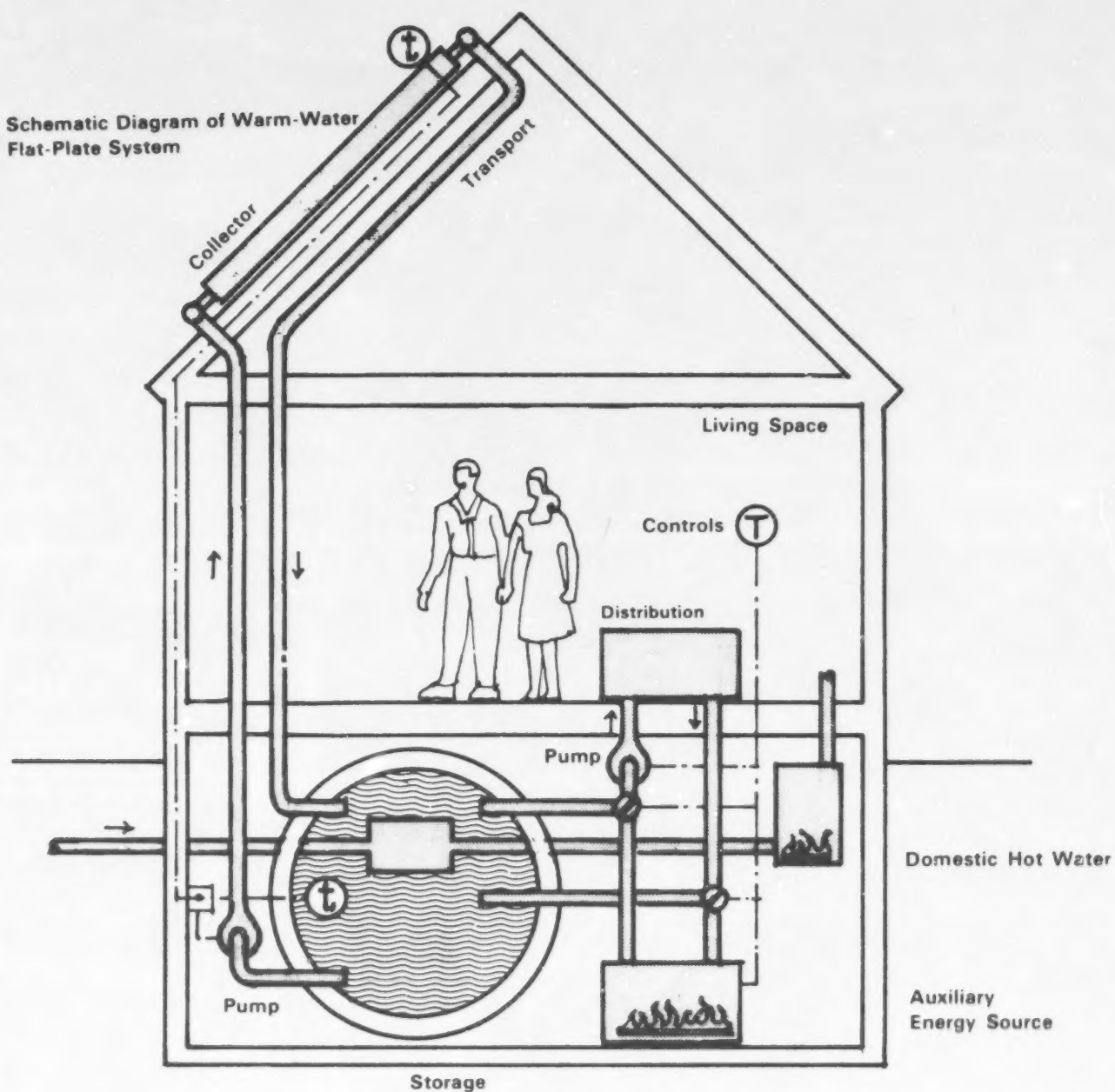
**Circular Concentrating Collector**



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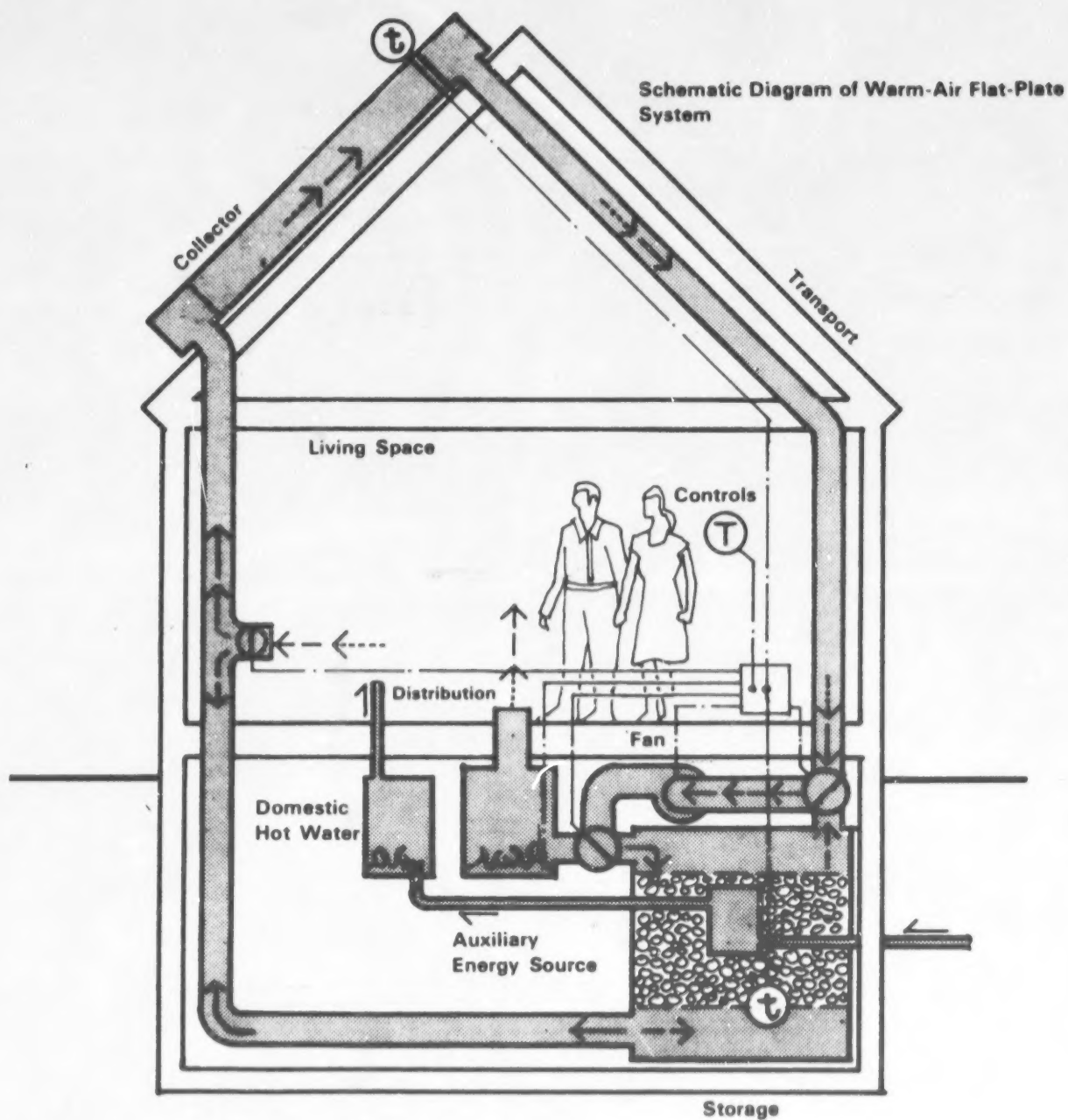
Schematic Diagram of Warm-Water Flat-Plate System



AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C.,  
Government Printing Office, May 1976.



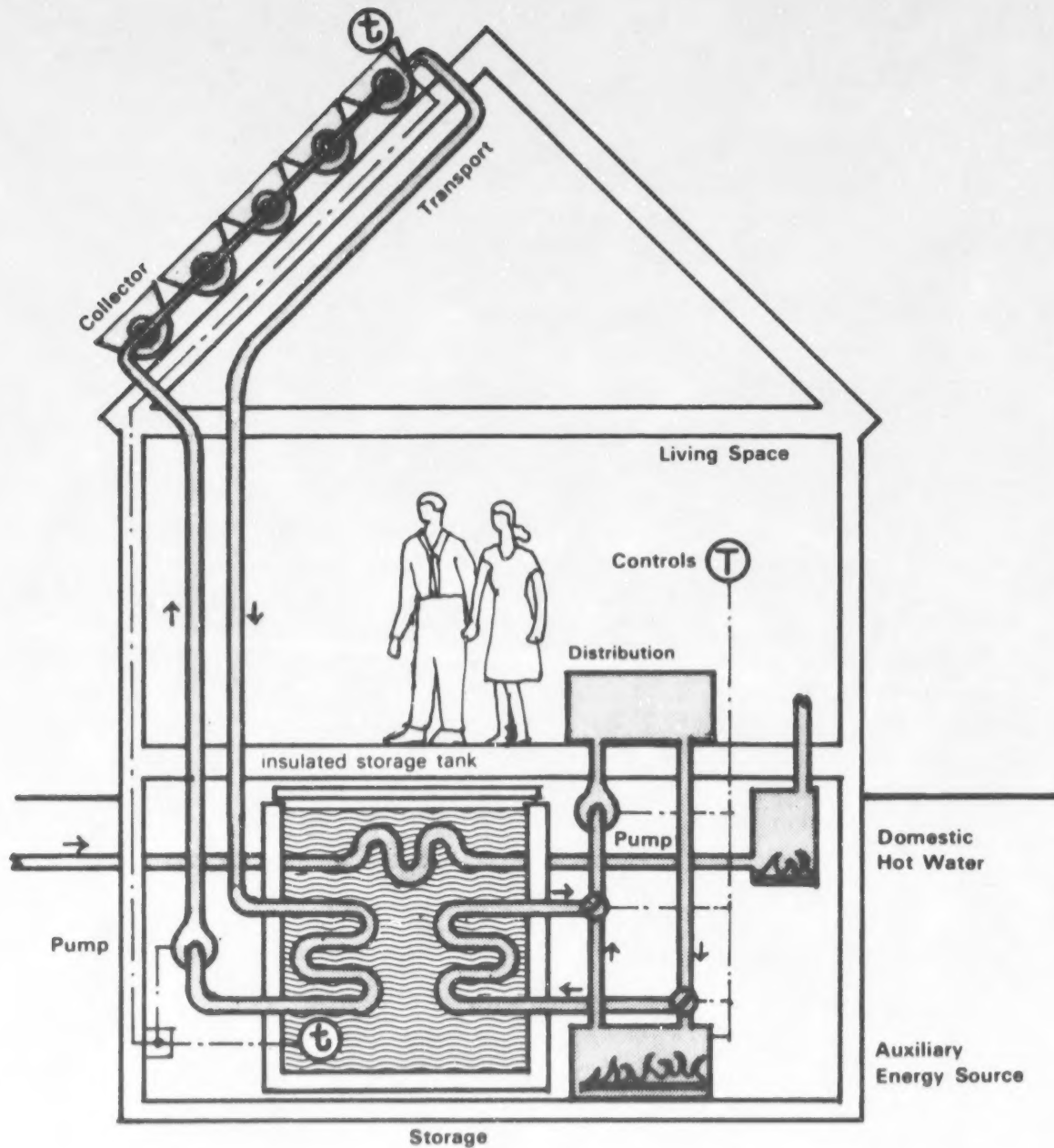
Transparency 7.2



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Transparency 7.3

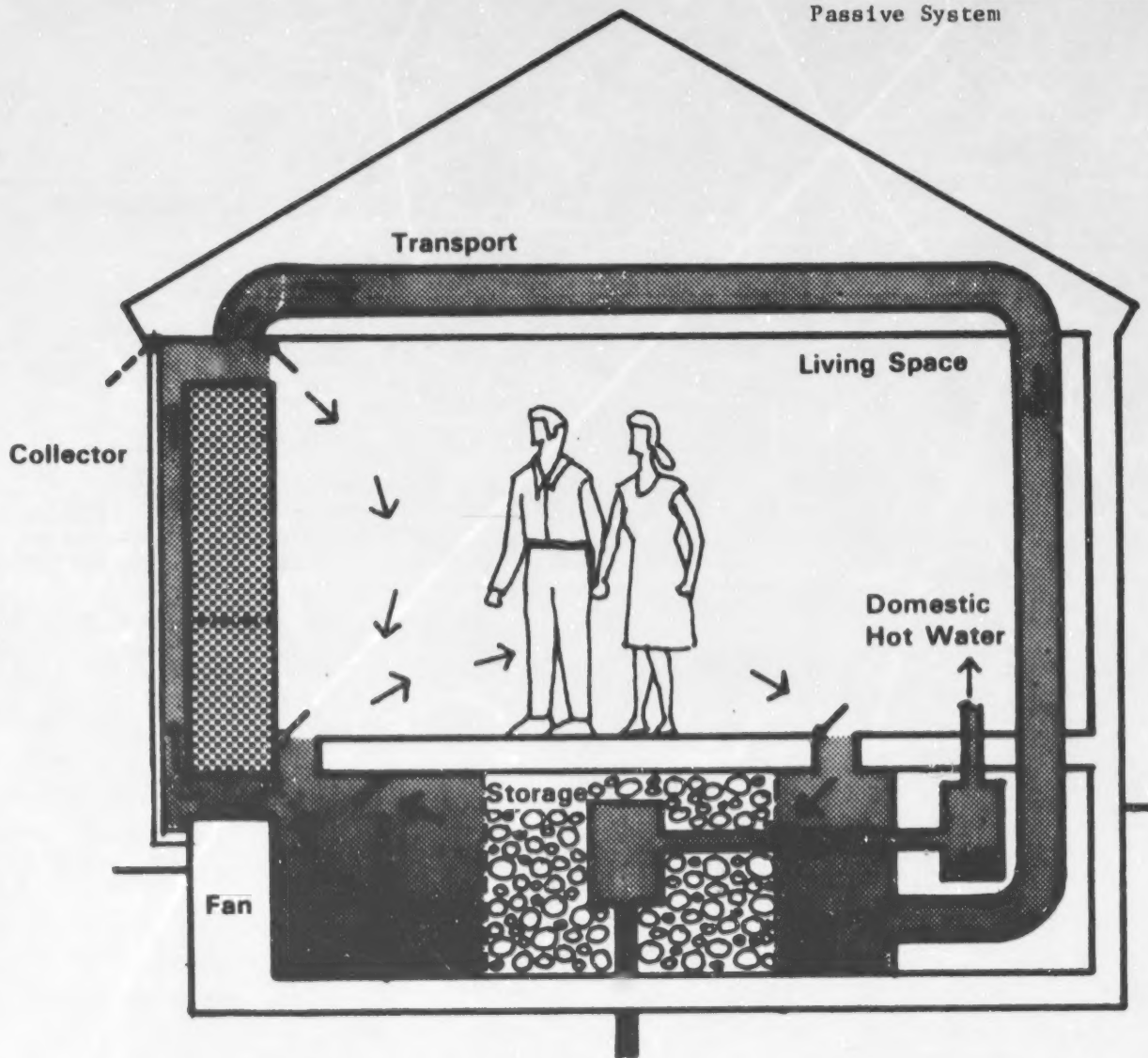
Schematic Diagram of Warm-Water  
Concentrating System



AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C.,  
Government Printing Office, May 1976.

Transparency 7.4

Schematic Diagram of Warm-Water  
Passive System



AIA Research Corporation, Solar Dwelling Design Concepts, Washington, D.C.,  
Government Printing Office, May 1976.